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4. STEPS INTO SPACE

"What seemed to be unrealizable for centuries, what yesterday was only an audacious dream today is becoming a real goal, and tomorrow -- an achievement."

S. P. Korolev

The first artificial earth satellite was launched into earth orbit on 4 October 1957. We evidently are still not in a position to fully appreciate the significance of this feat achieved by Soviet science, since its most important consequences will be revealed only in the future.

Mankind has entered a new, cosmic era. Today there is not a single aspect of human activity that directly or indirectly does not "work" in space. It has become obvious that man's space activities sooner or later will lead to the cosmicization of earth science and earth techology.

The advances made in astronautics are especially vital in appreciating the problems arising in relation to the matter of inhabited space. Before the beginning of space flights information on extra-terrestrial life could be obtained (excluding laboratory studies of meteorites) only indirectly. Today direct experiments on celestial bodies have become a reality. Study of extra-terrestrial life, its form, and nature are regarded as one of the principal goals of space biology. Astronautics is instilling hopes of the genuine possibility of the complete and comprehensive investigation of all aspects of a problem as complicated as inhabited space.

SPACECRAFT /216

K. P. Feoktistov, Cosmonaut-Pilot of the Soviet Union
and Doctor of Technical Sciences

I wish to address three questions in this article: on the closeness of the tasks of spacecraft construction and building an artificial "living" creature, on spacecraft of the future, and on the assignment of duties in spacecraft control between automatic devices and the crew.

A new field of technology has emerged before our eyes -- -- spacecraft technology. Its beginning was laid at the close of the 1950's by the building of the first spacecraft, Vostok, and then the Mercury, Voskhod, and Gemini spacecraft. Being relatively simple, and from the standpoint of engineers at the end of the 1960's and the beginning of the 1970's, these perhaps even simply primitive spacecraft already embodied the main features that are typical of spacecraft of the future.

Building a spacecraft is a typical integrated problem, complex and many-sided. In formulation, it approximates the task of building some highly organized creature intended to live and function over a very wide range of environmental and space conditions. Of course, one can find other, more innocuous analogies -- like an ocean-going vessel, and airliner, etc., but with the analogy I have chosen, it appears to me simpler to explain the difficulties and the diversity of the task.

What then are the characteristic features of a living creature?

-- Acquiring and processing information, exchanging information with other creatures, and thus the presence of organs to acquire information (eyes, ears, touch, small, and taste) and its processing (central and peripheral nervous systems).

-- The possibility of existing over a wide range of environmental conditions with the simultaneous maintenance within the organism of extremely stable conditions vital for the reliable functioning of the organism, and thus the presence of organs ensuring stable conditions within the organism (organs controlling heat exchange through skin, blood circulation, etc.).

-- The possibility of orientation and movement in space and the corresponding presence of organs for the control of orientation (eyes, vestibular apparatus, etc.) and locomotion (legs, wings, etc.).

-- Nutrition, that is, the possibility of replenishing energy outlays.

-- The provision for some excess or reserve of forces in the event of unforeseen circumstances, the possibility of controlling diseases and of recovering health even after serious traumas and diseases, the presence of a reserve of forces that will appear often in games and in other activity not aimed at achieving primitive material ends.

-- Automatic coordination and synchronization of the operation of internal organs. /217

Typical features of a spacecraft are these:

-- Acquiring and processing information about the ambient environment, on the spacecraft's attitude in space (angular and linear coordinates), and on the parameters of motion. The possibility of collecting "new" information and the appropriate "organs" to acquire it (measuring facilities, optical, gyroscopic, and radio instruments for scientific studies, etc.) and for processing information (calculating devices, on-board computers, and, finally, a crew).

-- Flight over a wide range of conditions (g-forces and vibrations during earth launch and during landing on the earth, high temperature during landing, vacuum during orbital flight, flux of light energy from the sun, and its absence in the shade of a planet, radiation, meteorites, etc.) and the appropriate facilities for sustaining stable conditions within the craft -- -- temperature, pressure, gas composition -- essential for crew life support and for the operation of on-board equipment (hermeticity of compartments, heat protection, devices for maintaining heat conditions and gas composition in the cabin, etc.).

-- Maneuverability needed to change direction and nature of motion, and the appropriate devices of angular orientation of the spacecraft in space (optical, gyroscopic, radio, and other devices with calculating units and systems of control devices -- microjet engines, hand wheels, etc.) and also devices for changing the craft's momentum (correcting motor installations, rocket stages, and electrojet engines on interplanetary expeditionary craft).

-- Nutrition, water supply, and oxygen supply for the crew, and also power supply for onboard equipment and the provision on board either of food reserves, or of devices providing for energy production and ensuring the partial or complete regeneration of stores consumed by the crew.

-- Structural strength reserves, redundancy of equipment, systems, and components, stores of energy exceeding those required as a minimum to achieve missions, regular execution of all kinds of test operations and of checking the serviceability of craft systems and units and of the ship complex as a whole.

-- Coordination and control of the operation of onboard systems, regulating their operating rhythm in various flight conditions and in different circumstances -- when there are changes in flight conditions.

These parallels can be extended, but those listed are sufficient for our purposes.

The analogies presented here at once enable us to imagine the total array of problems that must be solved and even the shape of the final solution. However, in addition to the requirements that are shared in common for any spacecraft, we must clearly also perceive and clearly formulate the goal that we pursue in solving a given problem.

The goals in building spacecraft will change with time and so will the technical devices resorted to in building spacecraft. /218

The first spacecraft (Vostok and Mercury) aimed at a very narrow and well-defined goal -- to make it possible to carry out manned flights in space along the orbits of an earth satellite and to carry out investigations to see what effect flight conditions have on the human organism. This formulation of the task then reduced its solution to several key problems:

-- to launch into an earth satellite orbit a manned craft (the problem of building a sufficiently powerful and reliable launch vehicle);

-- to bring the spacecraft from orbit back to the earth and to a landing (the principal goal was to provide protection against exposure to thermal fluxes during the descent into the atmosphere);

-- to provide for monitoring and the possibility of ground control of the craft's flight, since before the first flight it could not yet be asserted with confidence that man could control the craft's flight independently in conditions of weightlessness;

-- orientation of the craft in space and imparting to it collective (braking) momentum impulses needed to translate a spacecraft from an earth satellite orbit to a descent projectory passing into the dense rays of the atmosphere;

-- ensuring the conditions for the existence of an astronaut on board the spacecraft and the conditions for the functioning of onboard equipment (true, over a limited interval of time -- of the order of several days); and

-- power supply for onboard equipment.

The first problem was solved by using a powerful multistage rocket.

The problem of protecting the spacecraft's cabin against exposure to high thermal fluxes during descent was solved by using a special heat-protective material with which the cabin was covered.

To monitor flight trajectory, operation of on-board systems, and for ground control, use was made of radio devices developed based on the then-existing radio devices for measuring parameters of motion, telemetry, and control.

For orientation of the Vostok craft, use was made of a fundamentally very simple method of orientation of one of the craft axes toward the sun by using an optical sun-search sensor. A liquid jet engine was utilized to provide the correcting (braking) impulse.

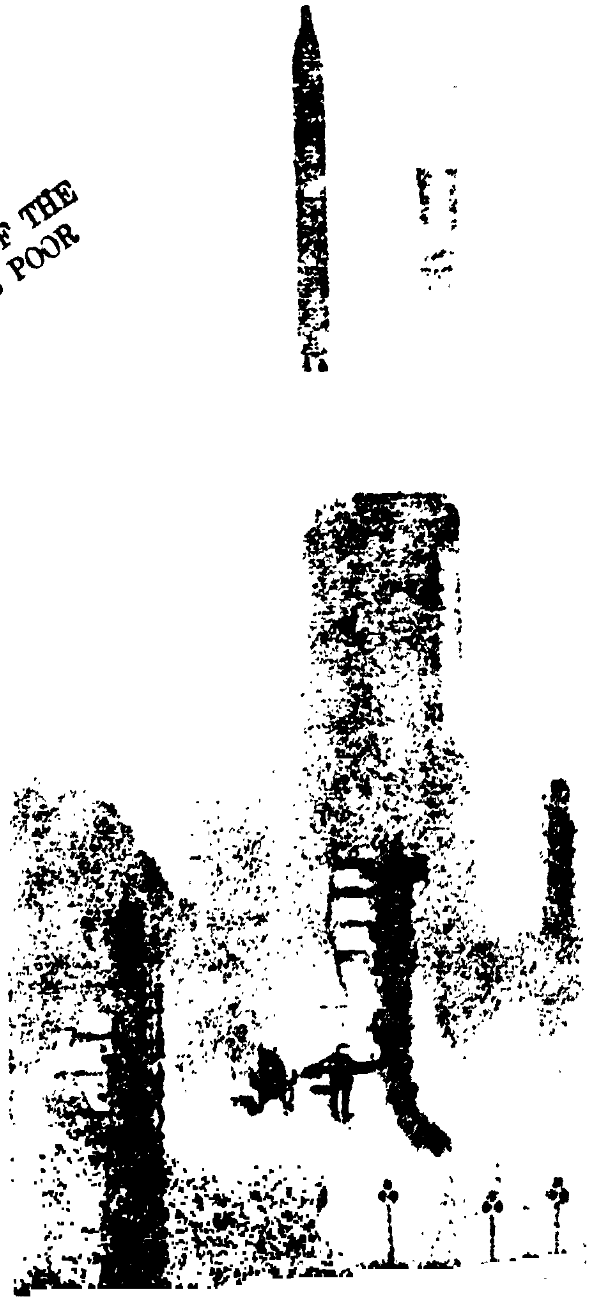
To sustain stable temperature conditions in the Vostok compartments, a system of thermal regulation was built. Thermal equilibrium between the energy emitted within the craft (due to the life activity of a cosmonaut and to the operation of on-board equipment) and heat exchange with the ambient environment was sustained by using a radiative radiator with louvers; by opening and closing these one could regulate the amount of heat emitted into space.

Heat was transmitted from the craft cabin to a radiative radiator by means of a liquid circulating in a closed loop. The temperature in the craft cabin was stabilized by regulating the /220 heat exchange in a gas-liquid heat-exchanger installed in the cabin and incorporated into the loop of the circulating coolant liquid. The gas composition in the craft cabin was maintained with a regenerating device absorbing moisture, carbon dioxide, and harmful gas impurities, and releasing oxygen.

Chemical batteries were used to supply power to onboard equipment.

Solutions to these main problems that were found in building the first spacecraft were quite simple. However, with growing complexity of future spacecraft these solutions will have to be re-examined and newer, more efficient ones found. Moreover, with changes in the missions of spacecraft new problems will be added to these.

Thus, in building the Apollo craft intended for landing an expedition on the moon, a number of new problems arose:



Two launches of spacecraft recorded on the same frame at an interval of 11 days. Right -- Gemini-7; Left -- Gemini-6

-- The insertion into earth satellite orbit of a spacecraft weighing tens of times more than the weight of the first spacecraft. This was necessary to provide fuel to the rocket stages used in accelerating the ship toward the moon, braking during the moon landing, and for the acceleration toward the earth.

-- Providing precise control over the spacecraft trajectory (in order to illustrate this problem, it is sufficient to refer to a single figure -- in returning to earth the craft must enter a "corridor" at the height of the standard perigee 10-20 km in width) and complicated craft maneuvering around the moon is required. The following classical scheme of landing an expedition of the planet is optimal from the standpoint of energetics: the insertion of the craft into a satellite orbit, separation from the craft, and descent onto the planet of a special cabin containing the crew, its liftoff into orbit, its rendezvous and docking with the craft, the passage of the crew into the craft, and the launch of the craft toward the earth.

-- Return of the craft into the earth's atmosphere at the second space velocity (about 13.5 km/sec instead of 7.5 km/sec during the descent from a shallow earth satellite orbit). This means that heat flows acting on the craft as it travels through the atmosphere will rise by a factor of 2-3 compared with the heat flows acting on a craft as it descends from an earth satellite orbit. /221

The range of problems will be greatly enlarged if we attempt to imagine spacecraft intended to bring an expedition, for example, onto Mars:

-- Insertion into earth satellite orbit of a craft weighing many hundreds of tons (or its assembly in an earth satellite orbit from individual units of lesser weight inserted into orbit one after the other).

-- This problem is intimately involved with the problem of energetics: for the acceleration toward Mars, braking at Mars, and for the return to the earth, the ship must in the different flight segments be given velocity increments amounting to a total of 15-25 km/sec (depending on the flight pattern), compared with 9 km/sec when the craft is inserted into earth satellite orbit.

-- Flight duration must also allow for the flight time to Mars, the time required to return to the earth, and the time spent waiting in the Mars satellite orbit (or on the planet surface) for the favorable position of Mars and the earth relative to each other for the ship's return to the earth (this time can be about 1.5 years) -- this time can be estimated at about three years.

With this schedule for the expedition, the problems of nutrition and water and oxygen supplies for the crew, and power supply for onboard systems change qualitatively; the problem of service life and reliability of onboard systems and the entire ship complex as a whole becomes markedly complex.

The flight pattern to Mars that is optimal from the standpoint of energetics, just as to the moon, is a flight pattern in which the ship enters Mars satellite orbit and only a special craft cabin lands on Mars, and the building of transporters to move around on /222
and explore the planet.

Solutions used in building Vostok craft will remain a classical example of simplicity and correspondence with the level of technology that serves as the basis for the appearance of the first spacecraft. But these solutions themselves can scarcely be kept as standard for the future -- further advances in spacecraft technology, accumulation of experience, and progress in other fields of science and technology will enable us to find more optimal and more reliable solutions. The possibilities here are great. We present several examples.

Return to the earth. Here progress is developing in the direction of building craft for controlled (and not ballistic) descent using aerodynamic lift. Here we talk about the need to markedly reduce g-forces during descent and to ensure exact landing in areas specified for spacecraft landing.

Power supply. A reduction in weight characteristics, an increase in operating service life, and a gain in power are the principal problems in advances in this field. Besides power supply systems employing solar batteries, fuel elements, and isotope thermogenerators, in the future obviously thermonuclear generators and more complicated nuclear power plants will be used.

Control of trajectory. Here we must anticipate advances in autonomic craft devices of measurement and processing using optical, television, and radio facilities in measurements (and using stars and planets as reference bodies) and onboard electronic computers -- -- for data processing.

Provision of thermal regime. In this case the problem lies in reducing the range of fluctuations in temperature in craft compartments. This will make it possible to use more complicated, lighter, and more compact components in the craft and increase their operating reliability (here it is convenient to recall that, for example, for a healthy individual body temperature is maintained with a precision of up to tenths of a degree).

To provide for the thermal regime, liquid loops equalizing the temperature fields along walls and other structural components of spacecraft, regulating the optical coefficients of radiation surfaces and radiators that are part of "hot" and "cold" loops of the thermal regulation systems can be used.

Ensuring life support of crews. This problem is particularly acute for extended flights. If during an expedition to Mars an attempt is made to solve this problem by means of reserves of food, water, and oxygen, then for an expedition of ten individuals it would be required to take along reserves having a total weight of about 70 tons (this does not allow for the possibility of the delay of the expedition).

Ways of solving these problems lie in regeneration and utilization of expended reserves. The task of regenerating water is relatively simple -- it is within the capability of today's level of modern technology. More complicated, but also fully accessible is the task of regenerating oxygen -- here the approach of biological regeneration can prove realistic (for example, using the simplest algae). /224

The problem of food can be solved by dehydrating it (with the simultaneous use of water regeneration).

A more radical way of ensuring crew life support in extended flights will evidently be to set up a closed ecological cycle on board the craft, ensuring during a flight the recycling of material (that is, the practically complete regeneration of food, water, and oxygen).

The problem of insertion into a flight trajectory, or the more general problem of the energetics of spacecraft travel. Today we can differentiate between a spacecraft and the launch vehicle. But why? In fact the craft begins its flight from the moment of launch, from the moment of liftoff from the earth, and over this flight segment the "rocket-spacecraft" system is a single whole. Perhaps the problem involves energy expenditures over different flight segments? But even here, for a lunar expedition spacecraft launching from an earth satellite orbit, the overall velocity increment over the entire flight segments must be approximately equal to the overall velocity imparted to the craft during its insertion into an earth satellite orbit, but for a Martian craft -- it is even substantially more.

The distinction between these concepts is accounted for by the level at which advances have been made in rocket and space technology. Present-day space complexes are substantially modified during their flight from earth launch to their return: over the flight segment of insertion into earth's satellite orbit, launch vehicle stages are successively separated, and then the craft itself parts from the last spent rocket stage. During the return to the earth, before atmospheric entry even the spacecraft itself separates into two or more parts, of which only the cabin (or, as it is sometimes called, the descent craft) containing its crew arrives at the earth's surface, having ejected even additional structural element before landing. Thus, whereas a system weighing a hundred tons had lifted off from the earth, now a descent craft weighing about one ton returns. The ratio of 1:100 most graphically shows how greatly modified is the system from liftoff to return. But for lunar and Martian craft, using chemical rockets, these ratios can rise to 1:1000 and even 1:10,000.

Is this good? We are reminded of an analogy with complex irreversible transitions that are experienced during life by several members of the animal kingdom: flying insects, eggs, larvae, cocoons, etc. During these transitions the safety of existence of these creatures is sharply reduced, which is quite natural. It is interesting to note that in living nature these forms of life with complicated transitions have not won a dominant position: obviously, they have proven to be less adapted than other living creatures that do not change so abruptly during their lifetime.

We must state that even in present space systems these transitions are not always reliable, which is accounted for by the complexity, nonsteady-state status, and irreversibility of processes ongoing during these transitions. If we formulate during flight time the probability of "undesirable events," then we detect peaks at the areas of transition. And the main thing is the irreversibility, the impossibility of repeating the most complicated processes.

These considerations suggest the following thought: could not we imagine a craft capable of being launched directly from the earth, entering into space flight, executing a landing on other planets, and returning to the earth without ejecting along its route most of its structure that can be used more than once (well, perhaps, with appropriate recharging and after necessary "preventive maintenance")? This would enable the craft to be more reliable and to be tested before "further" flights in testing facilities.

Here two avenues of development are possible, and evidently both will be tried out.

The first approach is to build orbital craft intended for flights in satellite orbits of planets and interflights between these orbits. These craft must be equipped with electrojet engines

Yuriy Gagarin returns from space. /223

(plasma or ionic types) with very high specific parameters -- -- with specific impulse (the ratio of an impulse of an engine to the consumption of working body per second) of the order of 10,000-15,000 units. These engines will evidently use as the source of energy nuclear reactors, though utilization of solar thermal generators with enormous surface areas is also conceivable.

Unfortunately, electrojet engines have very low thrust values -- of the order of kilograms or tens of kilograms, and therefore, they can be used only during orbital motion. A typical feature of the flight of such craft will be very extended engine operating segments. For example, the operating time of an electrojet engine during acceleration of a craft from earth satellite orbit to Mars or Venus will be reckoned in weeks. Therefore, their service life can scarcely be other than the main problem in building these engines. Orbital craft with electrojet engines will be virtually unchanged during flight. With advances in spacecraft technology, spacecraft of the type which are being built at the present time can be used along this approach to bringing a crew from earth to this kind of orbital craft and for return to earth.

The second approach is to build spacecraft that change only slightly during flight time -- from earth launch to return. These craft can be built on the basis of nuclear gas generators: the only condition is that nuclear-jet engines using the full power output of onboard reactors and hydrogen as the working body over flight segments where high thrust values are required (liftoff from planet surface) be developed. Specific thrust values of these engines must be of the order of 3,000 units. Electrojet engines can be used as the most effective for travel between planetary satellite orbits in these craft. Perhaps it may prove also useful to utilize high thrust values even for travel between planets, if engines with higher specific parameters can be built (this will permit shortening the time of interplanetary flights).

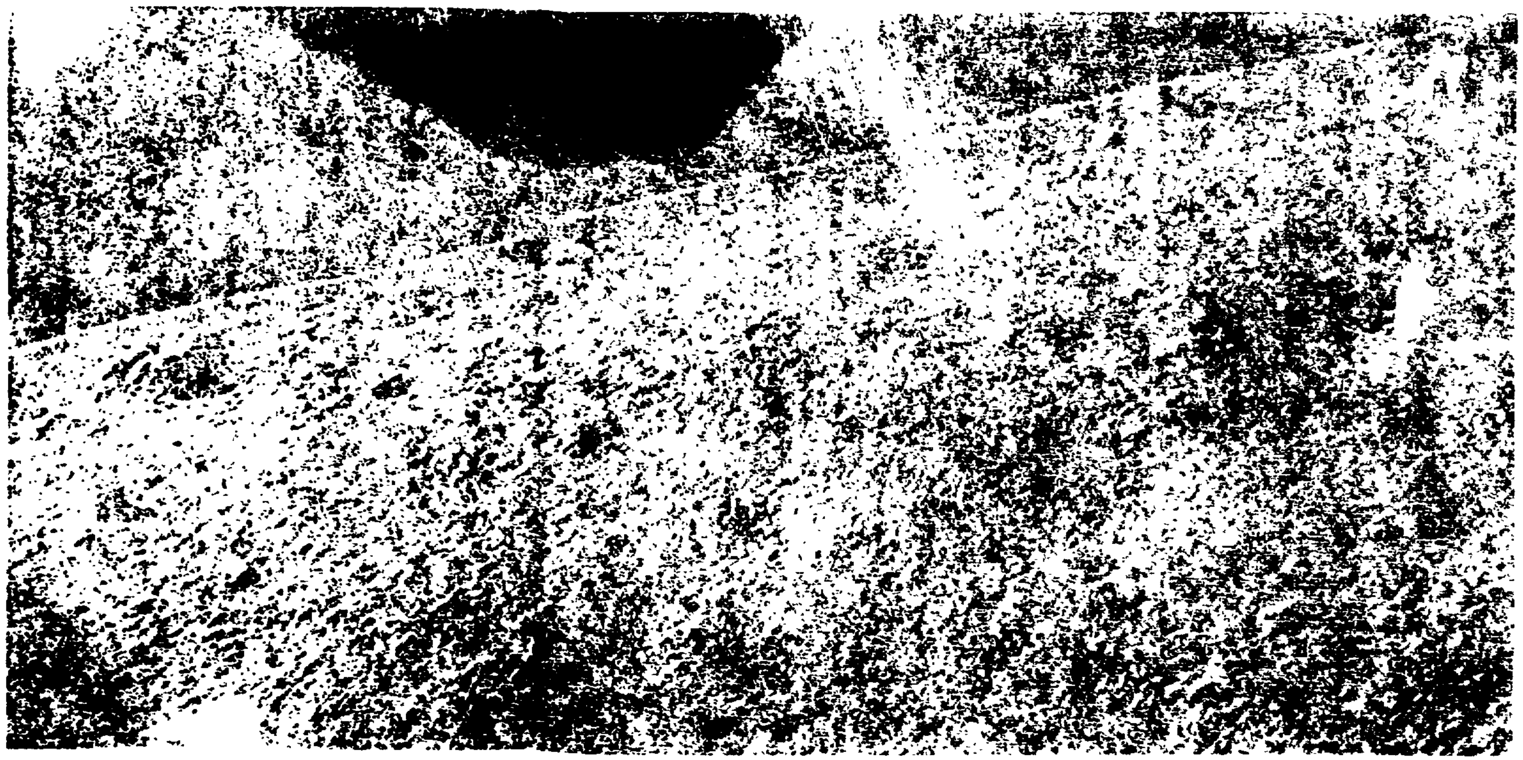
General problem of control. Here we refer to the main functions of control on a spacecraft.

Devices have already been built nearly entirely automating processes of monitoring and control on spacecraft (otherwise one could not launch automatic interplanetary stations to Mars and Venus and the first spacecraft in unmanned flights could not have been tested). True, we must note that close analysis of the condition of a craft and its systems is made by specialists thus far only on earth based on radiotelemetry data. The probability of complete and quite reliable automation of all control processes on the spacecraft, including matters of monitoring and analyzing the status of the ship and its systems, is possible.

But then what will be man's role in controlling the craft? In order to answer this question, let us examine one of the characteristic functions of control -- control of the craft orientation with pilot participation.

Control of craft orientation is carried out by the joint operation of the following components: sensing elements determining the craft's attitude in space (for example, optical sensors converting a measured deviation into an electrical signal); sensitive elements determining the angular velocity of a craft, displaying the result again in the form of an electrical signal; indicator devices -- instruments showing the pilot the values of measured signals; control levers transforming the movement of the pilot's hands working to electrical signals; amplifying digital-converting devices, transforming electrical signals from control levers into power movements of controlling units; and controlling units (for example, microjet engines).

It turns out that in this sequence of operating linkages man performs essentially a very primitive role of a computing component, processing acquired data into a control signal. And this is actually so.



Fragment of a panorama of the lunar surface first obtained from the Luna-9 Automatic Station.

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Perhaps man can replace other components? As a rule, no. Requirements placed on precision in the control of the spacecraft are so high that "eyeball" control is possible only in several very simple cases. Of course this does not mean that the control movement cannot and must not include man. But control can in no way be the principal function of man on board the craft -- he is being successfully replaced by a fairly simple computing system. /228

We can also examine the question of another important function of control -- monitoring and analysis of the status and operation of onboard equipment and systems. Before we can attempt to state that is precisely this function that is the crew's task, we must recall that dozens of specialists work on interpreting telemetry data transmitted during flight from onboard the spacecraft back to earth. Of course, in spacecraft of the future, the processing of data on the condition of a craft and its systems must be carried out on board. But actually by man? In fact then even on craft with large crews most of their time and energy will go into interpreting this information (voltage, power supply, correctness of functioning based on the results and the triggering time of numerous instruments and units, regulation of all kinds of dynamic processes -- gas composition, thermal regime of compartments and individual surfaces and ship devices, power supplied in the shipboard power line, craft orientation, etc.). Clearly, reliability of a proper enterpretation of the status of a ship by the crew will be increased if the crew will be relieved of primitive, but still very numerous functions in primary data processing, which can be successfully performed by the simplest analog automatic devices and electronic computing and analyzing machines.

Hence the following distribution of duties in control appears logical.

Automatic units will handle measurement, regulation of dynamic processes and operating rhythm, primary and generalizing monitoring of the status of a craft and its systems, and displaying to the crew processed information in general form: for example, "A-okay," or "A-okay, except ...."; monitoring of the condition of individual systems with the rating "Go" -- "No-go"; the status of parameters and functioning of individual systems (on crew request); recommendations on further crew actions; prediction of operation and status of systems; etc.

The crew will handle the selection and adoption of decisions on the further course of operations, flight, on required preventive measures, etc. -- in a word, the "right to choose" must be left to the crew. Of course, in the event of necessity the crew must be able to acquire primary data. But its processing is not a regular function, but an exceptional matter.

Large tasks in control must not be assigned to the crew, otherwise they will not have time for something else. In fact, in this case spacecraft control will be converted into an end in itself.

Acquiring new data, processing it, and on this basis again acquiring new data -- this is the main task of spacecraft crews.

FOR FUTURE SPACE FLIGHTS /220

A wide range of experiments with human participation have been carried out and are now underway in laboratories. These experiments simulate to some extent conditions in a spacecraft cabin. Young men with good health have been selected for the tests. During the experiments they were in a sealed chamber from 10 to 120 days. As the experiments were conducted on the individuals, in the chamber they were exposed to various combinations of ionizing radiation in small doses, and in some tests the temperatures were raised; noise effects were produced; and exposure to several other factors was studied.

Whereas under ordinary conditions the human organism depends on its environment, in a hermetically sealed room the opposite dependence becomes clearly evident -- the environment changes as the result of the organism's vital activity. And the environmental changes may even be unfavorable. During the test period it was found that skin undergoes some reduction in its protective properties against bacteria. Therefore, the microorganism count increases markedly on the skin, and more microbes are found in the air. Thus, during one of the tests, in 28 days the microbe count /221 in the air was increased severalfold.

During tests, certain changes developed in the human organism. This is particularly striking for experiments lasting 60 and 100 days.

In the initial period of the tests, the inhibitory process was enhanced in the cerebral cortex. Light sensitivity of the eyes and the speed of motor reactions were reduced in man. "Efficiency" also fell. During this same time (the first 10-13 days) some changes occurred in the operation of the heart; nocturnal sleep was disturbed. However, in subsequent days the organism adapted to the conditions of its new environment and its functions were gradually restored. After leaving the chamber, the changes again arose in the organism.

Four month tests showed that additional purification of air from bacteria and harmful chemical impurities, ultraviolet irradiation on the skin of persons undergoing the tests, the addition to food of large amounts of vitamins, and a special set of physical exercises and some drugs considerably reduced changes in the organism after the individuals had left the chamber.

LIFE IN SPACE /229

N. M. Sisakyan, Academician

In the history of mankind's scientific-technical triumphs, study of space holds a special place. Quite likely, it is difficult to find a discovery which would have as profound scientific and social-political consequences and would lead to such promise for comprehending natural phenomena as the beginning of the space age and the successful launch in the Soviet Union of the first artificial earth satellite.

Scientific data resulting from flights of satellites, space rockets, spacecraft, and interplanetary automatic stations are of the greatest value for world science. Scientific instruments installed on satellites, rockets, and automatic stations have brought data on the properties of remote space that had been inaccessible throughout the ages.

We have learned much that is new in recent years about the moon, about the properties and composition of electrically charged particles, the intensity of the magnetic field, the radiation bands surrounding the earth, the planets Venus and Mars, and other physical factors of space.

A typical feature of science in the 20th century is the fact that the greatest and most substantial advances have been the fruit of work done by large scientific teams, a result of which has been the thoughtful and purposeful planning and organization of research on the broadest scale.

Solving a truly grandiose past -- study and mastery of space -- has demonstrated to the entire world the exceptionally high level of progress in our own science and technology, which has enjoyed the constant attention and concern of our party, government, and the entire Soviet people. This clearly reveals the distinct advantages of the socialist order over the capitalist order for the incredibly rapid progress made in science and technology in the name of the good of mankind.

What does the conquest of space mean for mankind, and for his future generations?

All problems in astronautics and the prospects of its advancement are intriguing and boundless. But I have drawn closer to the biological sciences, and therefore I will dwell on biological problems of mastering space.

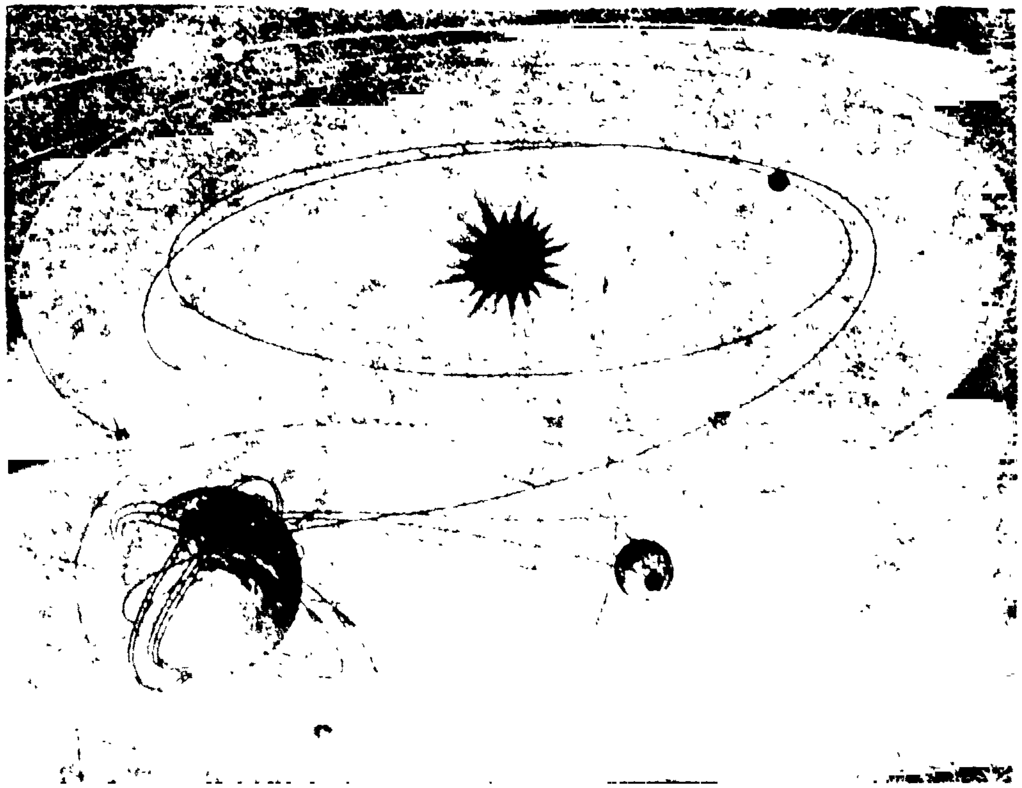
The universe! This word is full of enormous meaning. The boundless array of worlds associated by the same laws of motion. Matter in its continuous development is following different pathways. Life emerging on our planet is only one of the forms of its motion. About a million years ago man appeared, and with his labor and mind, he has transformed the face of the earth as time has elapsed. And now man -- a citizen of earth -- is becoming a citizen of the universe. What have the achievements in astronautics provided for the prospect of man's extra-atmospheric life, and can yet provide, and what -- of no less importance from my point of view -- can astronautics mean for the even broader study /230 of the essentials of life and the principal laws of its evolution in the universe?

The universe and life! These concepts are so closely linked that inevitably the thought arises: perhaps the interest in biological problems among scientists celebrated as investigators of the universe is not purely fortuitous. Copernicus graduated from a medical faculty and engaged in medical practice; Galileo received a medical education; and biological problems interested Lomonosov. And from its very beginning astronautics has been closely linked with biology. We know well how much attention was given to the problems of life in space by K. E. Tsiolkovskiy and F. A. Tsander. Remarkably, not less than a month after the launch of the first artificial earth satellite (4 October 1957), the first biological space experiment with the dog Laika on the second artificial earth satellite was accomplished (3 November 1957).

It is altogether obvious that man would have been unable to go into space without progress in space biology and medicine, which has encompassed all the most essential advances in modern science: physiology, biochemistry, radiobiology, aviation medicine, radioelectronics, and many other fields of knowledge. On the other hand, the advances made in astronautics provided a new powerful impetus for progress in biology itself and led to the introduction into biology of new principles, ideas, and methods. The penetration of man into space posed a number of entirely new and complicated problems for space biology, problems related to the flight and residence of man and living organisms in the special conditions of space, differing sharply from earth conditions familiar to us.

Here I would wish to briefly recount the results of biological work preceding manned flight into space and the main stages of flights made by Soviet cosmonauts. These investigations provided a wealth of valuable facts on the behavior of organisms in space, on the effect of factors of the space environment on physiological functions, and the hereditary qualities of various organisms. Before manned flight, studies were made on more than 15 animal and plant species. In selecting the animals, use was made of a broad evolutionary principle, which was combined with choosing living organisms with the aim of the biological indication of the effect of flight factors, and above all, the effect of ionizing radiation. The results enabled scientific principles for training and preparing cosmonauts to be developed, as well as a complex of devices ensuring conditions for normal life activity, full work output, rest, and safety during space flights.

Thus, scientific data accumulated by the spring of 1961 and the successful program of biological experiments on space satellites led to the conclusion that manned flight was possible in an orbit approximating a circle and lying deliberately below the earth's radiation belts. The space flight made by Yuriy Alekseyevich Gagarin on 12 April 1961, signaling the beginning of man's penetration into space, demonstrated the theoretical and practical possibility of ensuring the vital activity and full efficiency of a cosmonaut, and his active functioning in spacecraft control and in investigating space.



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With the launch of the first Soviet artificial earth satellites, direct investigations of bodies in the solar system using spacecraft were begun.

Subsequent flights of our cosmonauts on Vostok spacecraft, in addition to testing various life support systems, provided very valuable material on the possibility of multi-day flights and the related diurnal periodicities of physiological processes, on the possibility and effectiveness of group flights, and the coordinated activity of cosmonauts in two spacecraft. Here more careful study was given to problems of the selection, training, and conditioning of cosmonauts; in particular, conditioning of the vestibular apparatus for optimum tolerance of weightlessness. Finally, the space flight of the first woman -- V. V. Tereshkova -- was successfully carried out.

Flights of the Voskhod craft opened up the prospects for building space laboratories in which representatives of various specialties could carry out an extensive program of scientific research, including direct medical-biological studies in space by a specialist in space medicine. The world's first walk into open space by Cosmonaut A. A. Leonov made it possible to study many interesting theoretical problems in the physiology of human locomotion and his orientation in a referenceless space, the practical capabilities of human activity outside a ship, and also complex problems of ensuring his vital activity and efficiency in these conditions. /232

Experience already accumulated in medical-biological studies and manned flights in space convincingly show the boundless promise and the enormous role of man in the direct study and mastery of space and of celestial bodies.

Finally, the physiological space experiment with the dog Veterok and Ugolek on the Kosmos-110 satellite provided interesting data on shifts in animal metabolism during prolonged flight conditions, and on the possibility and limits to adaptation and the rearrangement of physiological self-regulation of functions.

The above-indicated types of studies laid the foundation for space biology, which is continuing to advance successfully not only in the interests of astronautics proper, but also, as will become more and more obvious, enriching the basic biological sciences with vital results for every day "earth experience."

We now have every reason to proceed to solving more complicated problems -- the basic biological problems of training man for interplanetary flights. Above all they include the following:

1. The study of the effect of prolonged flights in space on man and various living organisms; comparative analysis of the effect that the complex and various combinations of space flight factors have on an organism in relation to its physiological con- /233

dition and other characteristics; finding the conditions and factors that can adversely affect a ship's inhabitants; and developing appropriate measures and means of protection.

Space flight factors from the biological point of view can be divided into three groups: those associated with flight dynamics (g-forces, vibration, noise, and weightlessness); those characterizing space as a unique habitat (ultraviolet, infrared, and visible kinds of radiation, ionizing radiation, barometric pressure, uniqueness of thermal regime, etc.); and those associated with the longevity of an organism in artificial conditions of the hermetic spacecraft cabin (isolation, restriction of space, features of nutrition, diurnal periodicity, microclimate, etc.).

2. Medical support for more prolonged space flights, comprising together with engineers the scientific development of life support ystems, selection of the optimal gas medium, craft control, building devices monitoring hygienic parameters of the cabin, and the physiological indicators of the condition of crew members. This group also includes certain problems in public health, preventive and clinical medicine.

3. Developing adequate medical criteria for selecting spacecraft crew members, the most effective methods of their training and special kinds of conditioning aimed at increasing their tolerance when exposed to unusual factors. Here we also include psychological problems of prolonged residence of individual cosmonauts and collectives in unusual environmental conditions, work, and neuro-psychic tensions (stress).

4. Study of the biological essentials of support for prolonged space flights aimed at developing systems maintaining living conditions for a crew by simulating natural material-energy /234 ties of the human organism with terrestrial nature, carried out in the form of recycling of material using solar energy.

5. Study of conditions of life activity and forms of extraterrestrial life, and also dealing with problems associated with guarding against uncontrolled carrying of living matter into space and possible representatives of extra-terrestrial life onto our planet.

Current successes in the exploration and mastery of space represent the crowning triumph of science, the result of the overall high scientific-technical and cultural level of mankind, and the embodiment of all its historical experience. We can state that problems associated with man's entry into space are a kind of touchstone of the maturity of our science. For example, the successful experience in building systems for prolonged life support of man in laboratory experiments and partially in actual space flights is a criterion of the correctness of the fundamental ecological concepts and knowledge of modern biological science. At the same time they are expanding our ideas and concepts about the biosphere.

Today already, everyone knows well how much space studies are yielding for progress in astronomy, physics, geophysics, radio and television communications, meteorology, and many, many other disciplines. They obviously will reveal new sources of energy and material in space. All this doubtless will strengthen the power of man over the forces of nature and increase his well-being.

Biology and medicine are interested in mastering space, no less than other disciplines. Space studies provide favorable conditions both for the investigation of several fundamental problems in biology, as well as in solving problems in general biology and practical medicine. This can be illustrated with numerous examples.

Today it is not only the science fiction writers, but also representatives of many fields who await from space biology solutions to the most puzzling problem area -- how widely life is distributed in the universe, and what are its forms and characteristics. There are at least two ways of resolving the question of whether living matter is present in the universe. First of all, study of the possibilities of vital activity of different terrestrial organisms in laboratory conditions simulating the conditions of space and of celestial bodies. Present technology enables us to reproduce these conditions, and the main difficulties likely exist in the limitations of our knowledge on the nature of planets. Latest successes in space science and technology in studying physical conditions on the earth's nearest celestial bodies -- the moon, Venus, and Mars -- are of exceptionally great value in this respect. /235

At the same time we must intensify our efforts also in another direction -- searching for organic matter, substrates, and organisms outside the earth, both those similar to what exists on earth, as well as those different from them. Here we must be able to, as it were, "divorce ourselves" from several of the concepts and criteria of earth forms of life we have formed, since in space we can encounter forms of the motion of highly organized matter that will differ widely from terrestrial forms (for example, we can imagine that the foundation of the chemical structure of highly organized matter or forms of life will be not carbon, but silicon or some other element).

From the foregoing it follows how much more there yet must be done in searching for life in space. At present, paramount is the task of detecting and investigating microorganisms, spores, and elementary organic matter in space.

The prospect of comparing forms of life detected in space with terrestrial forms is highly intriguing to biologists. This will enable them to find the character and avenues in which living matter emerged and evolved in the universe and to confirm the general laws of the development of matter. /238

A more profound grasp of the essentials of life will enable us to modify organisms in a directed way by influencing their interaction with the environment.

During evolution, the organism of man and animals adapted well to conditions of existing on earth, in particular to earth gravity and exposure to cosmic radiation reaching the earth's surface. Biological experiments on spacecraft in weightlessness conditions and with more intense exposure to cosmic radiations will show what role these factors play and have played in individual and evolutionary development of organisms on earth. Also of interest will be biological experiments on planets that have masses greater than the earth's, and therefore, greater gravity.

Of much value for future space expeditions and settlements are also investigations aimed at the possibilities of regulating the intensity and rate at which life processes go on in the organism, in particular, investigating artificially produced states of hibernation and anabiosis.

Space biology and medicine are assisting in the progress of general-clinical medicine and public health. Let us recall the introduction to practice of new methods of functional diagnostics, of principles of occupational selection, the birth of new ideas related to the study of organismic responses to extremal factors, that is so essential for a better grasp of the pathogenesis of several diseases and their rational treatment.

Related to goals in astronautics, recent years have seen strong advances in theoretical and clinical labyrinthology, which is extremely vital in treating several human diseases associated with disorders of orientation in space, vertigo, etc.

Growing acceptance is being won by mathematical methods of research and medicine and the use of computers, which promises a solution to the most vital problem in continuous monitoring of the condition of seriously ill patients, introducing methods of providing emergency, including automatic, aid, and the like. /239

New methods of research open up more favorable possibilities for a profound study of work physiology. The study by space medicine of an organism's responses and behavior in extremal environmental conditions bears great value for the study of the vital medical problem of stress and the ability of an organism to adapt to extreme conditions of the environment and to maximum loads.

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Manned flight into space was preceded by experimental space flights of animals.

One of the most complicated problems in space biology is building a closed cycle for transforming matter in the spacecraft cabin -- simulating the existing recycling of material in nature. The possibility of successfully carrying out prolonged interplanetary flights is inconceivable without building artificial animal-plant communities incorporating man and satisfying his material-energy needs.

Advances achieved in formulating principles and methods of building closed ecological systems for spacecraft open up new possibilities for their use in the food industry, agriculture, etc. This is especially important now when no small part of mankind is continuing to experience shortages in foodstuffs.

Thus, modern biotechnology that has taken form as the result of the requirements of astronautics also promises to cooperate in solving many other urgent problems.

Problems vital to our planet, such as weather forecasting, the state of the ionosphere, and the sun service will also be solved in a new way. Building relay satellites and communications satellites would lead to a radical improvement in radio and television broadcasts over the entire globe. And this will open up vistas for publicizing scientific knowledge and culture, and for new forms of education and enlightenment of the world's masses.

If advances in aviation and progress in navigation led to bringing continents closer, we can assume that advances in rocket flight will lead to bringing planets closer.

I wish to stress strongly only the fact that if we take "inhabited space" as a future, remote goal, the path to "inhabited space" will be thorny and long.

At the present time only the first steps along this difficult, but promising path have been taken, which doubtless will lead to new triumphs in the conquest of space in the interests of peace, friendship, and well-being of the peoples of all countries.

TRIAL BY SOLITUDE. A NEW EXPERIMENT OF SOVIET SCIENTISTS /232

A. Romanov, TASS reviewer

Soviet scientists carried out an unusual experiment: they observed the life of subjects who spent a long time -- 70 days -- in a small specially equipped isolated room. One day three men entered a small room about 10 m^3 in size: a physician, Stanislav Bugrov, engineer Leonard Smirichevskiy, and a radio reporter Yevgeniy Tereshchenko, who kept a detailed diary of the events of all the 70 days. The subjects went through special training sessions. Shortly before the beginning of the experiment, each of the participants was given physiological and psychological "examinations". Then they were dressed in a special suit; all kinds of sensors were attached to the body of each in order for physicians to be able to keep track of the condition of the subjects. Biologists physicians and psychologists arranged a living regimen for the crew. The main element was work. Each day everyone took a four-hour work shift twice, performed navigational problems, worked with a sextant, carried out tests evaluating the mental condition of the individual, took photographs of flashing lights, and printed with a device resembling a typewriter. We know that /233 immobility caused by cramped conditions in a room is one of the difficulties that one must learn to overcome. In this case the role of the physical load is enormous. The room was provided with a bicycle machine. Exercising on it can be compared with a rapid climb on a bicycle up a mountain at an angle, let us say, of 30°. Each day 40 minutes was allotted for this session. Besides that, the subjects had an expander-chair. Working out on it also helped to maintain the necessary physical condition.

However, all this complex of physical loads proved to be clearly inadequate. The subjects encountered a fact of partial atrophy of their muscular system. Moreover, not only did physical, but also mental changes occurred in each of their organisms. Here is one of the pages from the diary, written three weeks after the "launch".

"Watch, dinner, medical checkup, sleep. Our life ticks on in a somewhat feverish, but monotonous rhythm. We have nearly no free time. But already you begin to feel exhaustion. Stanislav has lost weight, and circles have formed under his eyes. Leonard's eyes have reddened and are no longer restful-looking. Sometimes the ordinary amiable tone in our conversations disappears. Small /234 areas of misunderstanding arise, very similar to arguments, of course, all about nothing."

Here are new passages written a week after the lines above:

"Watch, dinner, checkup, sleep. Time is compressed, has grown shorter....you cannot tell one day from another. By degrees, nervous fatigue began building up. We are becoming more irritable. It is more difficult to force oneself to work. More and more often one wishes to open up a door somewhere and to see something different. Everything would be all right if there was only something new. Sometimes one goes into agonies wishing to see the bright, sharp, simple light of the spectrum or a calico sign, the blue sky. It's just boring."

Specialists modified the experiment and instead of the strict routine allowed an elective mode of life. From a certain day, everyone did only what he wished to do: read, play chess, etc. The only condition was to keep a time record of how his day went. However strange it may appear, the new routine proved to be more complicated than the old. Days, hours, minutes, began to drag on more slowly, one felt fatigue more clearly, and one's nervous tension rose. Sleep began to be troubled, auditory hallucinations began. At night one seemed to hear music, then singing, then the sound of aircraft. Once cacophonous music broke out in the chamber. It produced an unexpected result. Yevgeniy Tereshchenko wrote in /235 his diary: "I suddenly felt that one by one the bands that had been forged around my head due to the tension of recent days were being ripped off. And I began to feel lighter."

The experiment, as already stated, ended in 70 days.

The answer to the main question was in the affirmative. A small group in an enclosed limited space with everyday inconveniences, separated from the entire world, can live and function and preserve work discipline.

Later we met with the director of the experiment, V. A. Smirnov. Here is what he said:

"These 70 days were a test of will, spiritual qualities, and one's character for all the three. This was a test of each individually and of the entire group. I note with satisfaction that none of the subjects deviated from the outlined program; no one attempted to shirk his duties. In a word, this experiment demonstrated that man can live and function for many weeks under these conditions."

SPACE FLIGHTS AND THE PROGRESS OF MANKIND /238

A. A. Leonov, Cosmonaut-Pilot of the Soviet Union

One must also tell about another, indirect influence space flights have on the progress of mankind. We know that expanding the outlook of people, uplifting their general culture, and understanding man's place in nature are some of the conditions for eliminating any kind of psychological and social barriers between peoples which unfortunately still exists on the planet Earth. In this respect, space flights will be of great value, by vividly molding in peoples' minds the idea of their unity.

The living direct perception of the beauty of our planet, which I experienced, gave me the feeling that the earth is the Home of people, a sensation, a conviction of the indivisibility of mankind, of the fact that mankind can overcome conflicts yet existing, that people are equal in the face of the infinite universe and that they must conquer it for the sake of all people living on earth.

SPACE PSYCHOLOGY /240

V. V. Parin, Academician
F. D. Gorbov, Doctor of Medical Sciences
and
F. P. Kosmolinskiy, Candidate of Medical Sciences

At present space psychology is an independent scientific discipline with its own object of study and its own methods of investigation. Seen historically, it is subdivided into two key stages. The first corresponds to the time before manned flights into space, and the second corresponds to the time after the flight by Yu. A. Gagarin.

In the first stage there were only the possibilities of foreseeing the conditions of the first space flight, human responses to these conditions, and human adaptation to them, along with the directed activities of the cosmonaut.

In the second stage, the "prediction service" is retained in all its acuity. Everything that evidences a pioneering effort is related to it. However, a key feature of the second stage is the accumulation by now not of indirect, but of direct positive data. On Soviet and American flights, psychological studies were primarily involved with evaluating cosmonaut activity, while instrumented studies were short-term tests, not burdensome to man. Individual-psychological qualities such as space courage, the ability to relax when tense, self-possession, and self-control were also tested.

Among the numerous problems associated with the mastery of space, one of the most urgent is the problem of mental responses and the condition of an individual under conditions of extended flights to other planets and during residence on their surfaces. /241

The nature of these responses and condition is determined by the specific details in space flight conditions, of which the following factors are of special importance: the confinement of an individual in a small space; changes in three-dimensional orientation; effect on the organism of altered gravity (weightlessness); decrease in the intensity and number of sudden and internal afferent (sensory) nerve pulses; a sensation of novelty and danger; and a sense of separation from earth.

Psychological selection of astronauts embraces specific methods. In addition to the selection that is customary for medical psychopathology and neuropsychology based on contraindications, the highest individual-psychological traits of a personality are recorded. Therefore, the task of selection based on contraindications is combined with the task of selecting the best candidate most prepared for a given flight, and also in selecting spacecraft crew members on the principles of good compatibility and high level of interrelated performance.

It is important to establish ahead of time the capabilities of a cosmonaut-candidate, and to predict how he will tolerate the extreme flight conditions, sudden stimuli, and interference. Also studied are individual qualities such as space courage, responses to the novelty of an environment, the ability to continue operating duties in complicated conditions, etc.

Even before the first group flight (V. M. Komarov, K. P. Feoktistov, and B. B. Yegorov), it became clear that cosmonauts would have to be combined properly into a working collective -- into a team for success in this flight.

Camp outs, mountain climbs, and various kinds of group athletics (athletic games, rowing, etc.) showed how much such vital human traits as mutual respect, friendship, and well-coordinated performance mean to overall success. The history of soccer provides no small number of examples when terms composed of "superstars" were beaten by weaker, but on the other hand, more coordinated and friendly teams of players. /242

Studies of interrelated and interdependent cosmonaut activity have given birth to a new original direction in space psychology -- -- group psychology based on the "homeostat" method. It was found that one cannot predict the succes of the actions of a group as a whole based on the qualities of individual contributions. Abandoning isolated individual studies and switching over to methods of group psychology yielded a comparative estimate of the work done by different groups in terms of speed of response and of the strategy of the crew as a whole. Also, individual characteristics became more clear (with respect to the tactics of each group member in interrelated activity). The concept of tactics and strategy was invested with a quantitative expression, since the coefficient of interdependence is assigned from the control panel. This ensured that tasks of growing difficulty could be formulated.

Psychological selection was made easier by simulating space flight conditions. Such techniques as pressure chamber and anechoic chamber tests essentially served both for the purposes of selection and training goals. The same can be said also about other stand tests, for example, on the centrifuge, and also parachute jumps.

Through experimental-psychological studies, an approach was developed toward evaluating test results. Only signs of physiological discomfort with an abrupt drop in efficiency was rated as a negative indicator. From this derived the necessity of combined participation in experiments of psychoneurologists (observation), psychologists (setting up and producing the experiment), and neurophysiologists (recording and interpreting electrophysical, biochemical, and other data).

A space flight involves separation from the earth, from the human collective, from the entire environment that a person has been accustomed to from childhood, and cosmic flight is bound up with more or less protracted residence in a small closed space. /243

We know that animals on first entering a confining cage dream about trying to break out of it; a bird flying by chance into a room, loses its self-composure and in flight strikes against the walls and windows in trying to break through to freedom. Residence in a confining enclosed room is burdensome not only on an animal or bird, but also on man. The extreme degree of this neuropsychic experience is well familiar to psychiatrists and psychologists and is called claustrophobia, that is, a fear of enclosed space.

Therefore, it is not fortuitous in cosmonaut selection and training, in particular, for claustrophobia testing, that the anechoic chamber has become part of cosmic psychology and medicine. This is a small room which is tightly closed during the period of investigation. The anechoic chamber is constructed of soundproof materials; deep silence reigns in it; the anechoic chamber is illuminated with artificial light; visual contact with the outer world is absent; and in it are situated instruments and equipment with which the cosmonauts are trained. Thus, man in an anechoic chamber can be studied under conditions in which the input of external impressions is limited to the maximum, and this, just like the enclosed state, has far from an indifferent effect on man.

To keep up a high vital tone, efficiency, and good attitude, one needs a sufficient influx of external impressions or sensory stimuli. Sight, hearing, taste, touch, and feeling enable man not only to recognize the external world, but also to orient himself within it -- with their aid the brain, as it were, charges itself with energy. Sensory stimuli can be figuratively compared with a food which satisfies the brain, and the condition of the brain when this "food" is deficient -- can be compared with starvation. So we speak of sensory hunger or sensory deficiency (deprivation), or else of the insufficiency of the input of external stimuli. /244

Tolerance to sensory hunger is checked and conditioned for in the anechoic chamber; in the anechoic chamber man learns self-control, studies how to precisely calculate his time, and how to fall asleep and wake up independently and precisely on given schedules.

Eidetic (image) ideas and illusions associated with the improper evaluation of stimuli whose informational characteristics are inadequate for their recognition can serve as psychophysiological models of pathology in perception in an anechoic chamber. Eidetic ideas formed sometimes reach nearly the state of actuality. However, they differ from hallucinations, since an individual in a chamber knows that this is the fruit of his imagination and that at any moment he can escape from them. An incorrect interpretation of unclear stimuli, for example, auditory, leads to erroneous concepts and causes deception of the emotions.

Conditions of isolation limiting the circle of interests can serve as soil in which "supervaluable ideas" arise, which it is true can be readily abandoned by switching over to ordinary working conditions.

The effect of the factors of social isolation and sensory hunger can be evaluated not only in anechoic chamber studies, but also during the time spent by expeditions in remote locales (deserts and the transpolar region), in extended submarine voyages, in studying the responses of speleologists separated from their ground bases, etc.

Of interest are data of Polish scientists on the reaction of high-altitude pilots to factors such as isolation (the loss of direct contact with the earth and other persons), monotonous flight environment, and residence in a confined aircraft cabin. In 36 percent of the cases pilots were observed to show unpleasant responses to the sensation of loneliness, separation from the earth, and also other emotional responses -- uneasiness, stress, lack of confidence, and fear. The effect of isolation can be brief or prolonged. In the former case, this gives rise to errors in piloting, illusions, and loss of spatial orientation. In the second case, behavioral changes develop (emotional instability, neuroses, etc.). /245

With increases in flight velocity and altitude, the problem of man's orientation in ambient space takes on growing importance.

Each healthy individual has the sense of "body scheme." By this we mean the generalized idea we have of our bodies, their size, and orientation in space at each given moment. An individual also includes his clothing and footwear in the "body scheme."

Therefore, the pressure suit is also included in this scheme by the astronauts. Somewhat arbitrarily it can be assumed that even the spacecraft as a whole is incorporated by the astronaut in his "body scheme" during the flight.

To formulate a specific "body scheme" under these conditions requires a special "accommodation", the ability to adapt rapidly, which involves overcoming certain difficulties. They become much greater when the position of the support area changes, for example, during accelerations. Special conditions are produced during weightlessness. Adaptation to changes in pressure on the support area takes place as a reflex, without conscious participation.

During unstable equilibrium, psychological difficulties can arise, showing up in neuro-emotional tension. General muscular stress appears; the gripping reflex becomes stronger (in a pilot this leads to gripping the aircraft control stick). The inception of false perceptions of spatial attitude is also associated with muscular stress. Special training (physical and parachutes) provides help in controlling muscular stress.

There are grounds to assume that overcoming the "sticky" reactions of muscular stress by training involves the timely, profoundly dynamic formation of physiological systems of foresight in the brain. /246

The problem of the relationship between and space understandably is not exhausted by what we have said. However, the foregoing is sufficient for us to formulate a principle about spatial stress. By this we mean the difficulties and forces that arise in an individual associated with residence, movement, and actions in space as a function of the structure and organization of the ambient spatial field and the presence in it of any objects and creatures.

Physical and parachute training and the "rehearsal" of a flight in one's imagination -- all this helps in formulating a complicated scheme of interactions in the "man-ship-ambient space" system and promotes an eliminating or reducing of spatial tension.

In selecting cosmonaut candidates, a great deal of attention is given, in particular, to parachute training. Before a jump, experienced parachutists are observed to show an increase in organism reactivity, after which follows an abrupt drop in this indicator. Scientists conclude that after multiple repetition of dangerous situations a process of psychophysiological inhibition develops. The initial rise in reactivity automatically provides for the timely appearance of a danger signal, while the inhibitory reaction promotes preservation of the state of vigilance. In this way a mechanism of adaptation to overcoming the threatening danger is produced.

Extreme factors of space flight and extreme conditions of existence in space bring about a considerable psychophysiological stress in astronauts. Reactions to the novelty of the environment, to abrupt environmental changes, and to flight hazards are expressed in excitation of the neuro-emotional sphere and in appreciable functional shifts in the endocrinal system. We know /247 that the heartbeat rate and respiratory rate rise sharply over the powered segment of space flight projectories (during takeoff and during landing).

Several workers have noted the condition of stress in subjects in an anechoic chamber. The condition of psychic stress in severe isolation proves to be so intense that many cannot withstand the experiment and ask for it to be terminated prematurely. Prolonged joint residence in a spacecraft cabin can be a reason for psychic stress in crew members. Intense emotional experiences (positive as well as negative) can also bring about complications. In a spacecraft cabin it will be difficult to cope with these experiences, while on earth they are relatively easily suppressed with a change in scene. Evidently, one must avoid including in crews persons with unstable nervous systems and exhibiting schizoid character traits.

Work done in several Soviet and foreign laboratories on the use of autosuggestion for these purposes are highly promising in relation to the necessity of preventing stress states during space flights. From the data of A. I. Svyadoshch (USSR), after 2-3 months of special exercises one can, as desired, induce in oneself a rise or fall in the temperature of the skin on the wrists by 1-2°, and alter a muscle tone and heartbeat rate. By autosuggestion one can eliminate an anxious state, severely reduce neuro-emotional stress, and teach oneself to rapidly fall asleep or awake at the right times.

Investigations showed that preliminary stressing of muscles appreciably heightens their ability for subsequent spontaneous relaxation. Exercises in stressing and relaxing muscles with the attention being focused on the sensation of relaxation promotes the formation of habits of more complete relaxation. In this way a feeling of being under pressure is overcome. In turn, this promotes the preservation of fine coordination of movements /248 during emotional influences. Even in the event of intense emotional stress, establishing a quiet breathing rhythm with a somewhat prolonged exhalation phase promotes the normalization of autonomic functions -- pulse rate, blood pressure, galvanic skin reaction, etc. With normalization of autonomic functions, stability of mental functions is also enhanced.

Special conditions of the existence and performance of astronauts in prolonged flights pose serious requirements on developing optimal regimes of work, active recreation, and sleep. The need has arisen to summarize data relating to this problem and to formulate an integrated concept of "space days." This analysis was successfully carried out by B. S. Alyakrinskiy, who presents a number of conditions influencing the organization of diurnal regime onboard a spacecraft. The most important of these are the following: the design of spacecraft cabins (in particular, work stations and recreation areas for astronauts); the occupational performance of astronauts, and their muscular activities; crew size; individual-psychological traits of each astronaut, etc. The author proposed a classification of possible variants of an artificial diurnal rhythm for future cosmic space flights.

Underlying the classification was the conviction that 24-hour days can be regarded as the optimal variant. By changing the number of hours in "space days," one gets elongated and shortened days. Both kinds of days can be utilized as static or dynamic days. Static days represent the ordering of life which remains unchanged for a long time. On dynamic days the duration of individual cycles (sleep, active recreation, and work) changes. All these day variants can be called simple in contrast to mixed days, which essentially consist of an individual living for a certain length of time according to a program of dissimilar days, for example: 12-hour days, then 8-hour days, further, 18-hour days, etc.

Investigations revealed man's ability to adapt to any diurnal periodicity. This however, does not mean that the adaptation occurs easily. Moreover, the adaptation of an individual to a diurnal rhythm unfamiliar to him often proves to be a process of exceptional length and difficulty, and above all -- in the area of mental activity. /249

An accelerated rhythm of change of sleep and vigilance in 18-hour experimental days produced inexact ideas of the distribution and duration of time in subjects. A marked acceleration in the rhythm of performance in multi-day chamber experiments was noted, with shortened periods of activity, sleep, and active recreation. Here the required volume of work was performed in full.

There are many ways of teaching the "sense of time" and the organization of a proper working rhythm. One of the possible variants in this direction, in the view of Soviet scientist G. K. Mikushkin, is to train astronauts on earth under conditions that are as close as possible to space conditions. This is achieved by simulating in the spacecraft training cabin terrestrial, familiar conditions of space and time. In particular, it is proposed to develop in astronauts, based on the visual, auditory, and vestibular analyzers, conditioned-reflex stable forms of response, which underlie perception of space and time.

Problems in space psychology will more and more interest researchers as progress is made in astronautics. This field of science has only just gotten underway, and it has a great future.

DEPTH PERCEPTION IN SPACE /240

A. A. Leonov, Cosmonaut-Pilot of the Soviet Union

Mastery of near-earth space has made it possible for mankind to take a giant step forward in solving purely earthly problems in which everyone is interested: weather prediction, establishing global systems of communications, and so on. Solving more complicated problems requires further penetration into space. First of all, to carry out such grandiose intentions we need to set up near-earth orbital stations. Here we cannot get by without solving problems of controlling rendezvous and docking in the assembly orbit of modules, and arranging for welding and other technological and production operations. Most of these operations will be carried out outside the spacecraft.

From this it follows how urgent it becomes to find man's capabilities of properly perceiving spatial relationships of objects outside the earth. Without this, astronaut activity and safety are inconceivable. In aviation practice there are numerous examples of flight incidents occurring due to the illusory perception of reality, and primarily spatial relationships.

Man's first entry into outer space has provided much material /241 for understanding how depth perception takes place in these conditions and what must be done for reliable orientation and effective work performance outside a ship.

There is reason to recall how K. E. Tsiolkovskiy represented egress from a spacecraft. The hero of his science fiction novel, Vne Zemli /Away From Earth/ states: "When I opened the outer door and I found myself at the threshold of the rocket, I was horror-struck and made a convulsive movement, which then pushed me out of the rocket. It appears I was already accustomed to hanging without supports between the walls of this cabin, but when I saw that before me was an abyss, that nowhere around me was there any support -- I acted foolishly and I collected myself only at the moment when my entire cord had already unwound and I was a kilometer away from my rocket...."

Well, Tsiolkovskiy foresaw that leaving a spacecraft will be fraught with overcoming the "fear of space." This human response developed during life experience and perhaps inherited from our ancestors actually exists. That is why in preparing for flight I underwent a complex of training sessions, consisting of special physical exercises, parachute jumps, and flights on jet /242 aircraft, along with flights in a flying laboratory where under conditions of brief weightlessness I worked through all of the sequence of cosmonaut actions on leaving the airlock chamber into outer space and returning back to the ship. As a result, on leaving the ship's airlock, the sensation of "psychological barrier" did not occur in my case. The moment of the first separation from the ship and the first step into space was not accompanied, as would be expected, by an abrupt flare-up of emotional stress. This is indicated not only by my subjective impressions, but also by the data of telemetry recording of several psychophysiological parameters (electrocardiogram, electroencephalogram, respiration, and so on).

As soon as the outer hatch of the airlock of the Voskhod-2 spacecraft opened, boundless space presented before me a view with all its indescribable beauty. The earth floated grandly in front of my eyes and appeared flat, but only the curvature along the edges reminded one that it was still a globe. In spite of the quite opaque-like filter of the illuminator in my pressure helmet, clouds, the smooth surface of the Black Sea, fragments of coastlines, the Caucasus Range, and the Novorossiyskaya Bay were visible.

On leaving the airlock and on generally pushing myself /243 off, I moved away from the ship. The mooring line by means of which I was secured to the spacecraft and maintained communications with it stretched out slowly to its full length. A gentle exertion as I pushed off from the spacecraft led to its slight angular displacement. Voskhod-2 was bathed with the rays of the sun. No sharp contrasts of light and shadow were observed, since the parts of the ship in shadow were quite well illuminated by rays reflected from the earth. Splendid green masses, rivers, and mountains floated by. The sensation was about the same as I had in an aircraft when I flew at a high altitude. But owing to the sizable distance, it was impossible to make out cities and details of terrain, and owing to this it appeared as if you are floating over an enormous beautiful map.

I had to move around the craft flying at space velocity over a rotating earth. I moved away from the craft back first at an inclination of 45° to the longitudinal axis of my line and I came up to the ship head first with arms extended in order not to strike the ship with my helmet illuminator (or to "sprawl" over the craft as in free fall during parachute jump). During movements I had to orient myself in space with respect to the moving /244 ship and the "standing" sun, which was overhead or behind my back.

On earth a system of coordinates with the ship as the "bottom" was already developed for orientation outside a spacecraft. This representation was "matured" during flight preparation. Several dozens of schemes were drawn in which all possible versions of the attitude of the cosmonaut in supportless space relative to the ship, sun, and earth were worked out. With special training sessions and also using flights to achieve weightlessness in a flying laboratory with a simulator of a spacecraft, the psychological representation of the ship as the "bottom" was refined and reinforced. It persisted also during the excursion from an actual spacecraft.

In one of the excursions, as a result of pushing off from the ship a complicated twisting of the transverse and longitudinal body axes occurred. Flashing stars against the background of dark-violet, bottomless sky with overtones of velvet blackness, floated in front of my eyes. Sometimes only two stars entered my field of view. The sight of the star was replaced by the sight of the earth and the sun. The sun was very bright and appeared as if it was "nailed" into the darkness of the sky. It was impossible to stop rotating by resorting to any movement /24 whatever. The angular velocity decreased only with twisting of the mooring line. During the time of rotation, even though the ship was not visible the representation of its location was preserved entirely and no disorientation was observed.

It must be noted that in spite of numerous training sessions, complete automatization of coordinate concepts of space, in which the ship is "bottom", did not occur. In order to remember at each moment where the ship was (when it was invisible to me), I had to carry out a kind of mental "charting" of my route considering at which angle I had moved away from the ship, by how many degrees I had turned, and so on. The reverse concept of the geometrical relationships between heavenly bodies visible at a given moment (stars, sun, and earth) and the invisible ship also was part of the complex of psychological processes providing for orientation. The mooring line was also a good orienter, when it was completely wound up. This method of orientation made it possible to carry out all the tasks facing me. However, it still did not represent a considerable portion of my attention, and later evidently we must have a special signaling device which would /246 continuously supply the cosmonaut with information about his bearing toward the standard "bottom".

More complicated problems of the formation of spatial concepts of the new "reference" coordinate system would emerge when assembly operations are carried out in outer space on various objects.

In this case it would have to have not one, but two (or more) systems of coordinate representations with different "reference" coordinates. For example, when working around a ship the "bottom" must be the ship, but when working around an orbital station moving at some distance, the "bottom" must be the moving orbital station.

Studies by psychologists showed that "switching" from one system of coordinate representations to another is a complicated matter.

In earth conditions spatial concepts of man are formed and reinforced on the basis of combination of the function of stato-kinetic (vestibular), proprioceptive, skin-mechanical, intero-ceptive, and optical analyzers. In space conditions, as the result of the appearance of weightlessness the main source of adequate information on the spatial position of an individual /247 becomes the optical analyzer. This leads to a rearrangement of the system of orientation developed in the central nervous system over centuries. On entering conditions of weightlessness, an individual must develop new concepts, a new "subjective model" of coordinates. On earth people in some professions also need to rearrange their usual system of coordinate representations. Without doing this, divers cannot function, acrobats cannot perform somersaults, and ballerinas cannot dance.

But in weightlessness the problem becomes much more complicated.

For a person in open space the problem of orientation is complicated even further by the fact that sensations associated with contact against parts and support carriers in the cabin fade away completely. Moreover, even for visual "reference", an unusual reference coordinate must be developed -- the "bottom", which can be either the shape of the ship, or the earth, or the moon. It is not wholly clear how to better formulate several "points of view" essential in carrying out assembly operations in orbit and to provide rapid and reliable conversion from one to the other at the necessary times. However, the fundamental possibility of this, deriving from the psychophysiological theory of a fixed and unfixed environment and the principles of /248 the formation of complex images, was confirmed during the first egress into space.

Incidentally, one of my observations, in the view of psychologists, clearly illustrates the importance of a fixed environment in the mechanism of stereoscopic depth visual perception of space. As we know, when we look at the night sky from the earth the stars appeared to be against the dome of the sky at an identical distance from us. In space however, I was apparently "bathing" in a expansive starry world. Bright stars seemed to be close, while stars of weak brightness appeared to be far-off. Evidently, this is accounted for by the fact that owing to the effect of self-absorption by the atmosphere, the range of visible stellar brightness is markedly increased compared with "terrestrial" impressions. I note that this illusion does not interfere with the three-dimensional orientation of a cosmonaut.

Thus, human depth perception in space has many points of distinction. It is most vital to take allowance of them when a cosmonaut performs operations outside his ship.

DETECTION OF LIFE IN SPACE /250

W. Corliss, professor (United States)

Is there life in the universe? In the immediate future an attempt will be made to find it. One must also formulate the most suitable criteria for the presence of living matter, that is, one must know how to pose questions in order to uncover this secret, and how to interpret answers to these questions. Moreover, if living matter existing somewhere has a different qualitative and structural chemical composition and, therefore, entirely different compounds participate in nutrition, respiration, and excretion, the positive response of automatic equipment operating according to the program of "earth criteria" generally speaking cannot be obtained.

During the centuries, scientists and philosophers have shared diametrally opposite points of view: some held that life exists only on earth, while others held that it exists also outside the earth. Today some indirect data have been obtained apparently indicating the possibility of life and even civilization outside the earth. However, scientists are increasingly inclined to the view that extra-terrestrial life is possible not so much because of the new knowledge, as because of the fact that life on earth has proven to be exceptionally tough, rich in forms, and amazingly capable of adaptation.

By the "detection of life" we must mean obtaining an unambiguous answer: "Yes" or "No". Actually, today we do not have an instrument that could determine forms on the borderline of life. The best that we can hope for is only an inconclusive suggestion.

Let us assume that a rocket lands on Mars and radios back to earth that amino acids exist in samples taken. Can we then state that life exists on Mars? No, we can only say that there is a positive indication. But if proteins were detected, then this would give additional weight to the assumption of the probability of life. Bacteria observed under a microscope can seem to be an irrefutable proof of life for many, but the possibility is not to be excluded that the bacteria may have been brought there from earth in equipment that was not adequately sterilized.

Thus, indications pointing to the possibility that life exists on another planet will always give rise to the broadest discussion among scientists.

To solve the problem of detecting life outside the earth, one needs to properly phrase the questions, which can be divided into three large groups:

1) detection on planets of chemical compounds similar to amino acids and proteins, which are usually associated with life on earth; /251

2) detection of signs of metabolism -- whether nutrients of the earth type are absorbed by extra-terrestrial forms; and

3) detection of forms of life similar to earth animals, and impressions of life forms in the form of fossils, or signs of civilizations.

It is possible that somewhere living creatures possessing properties differing greatly from the typical earth world of life exist. In fact even on earth there are living organisms (bacteria) which are difficult to regard as normal from the standpoint of common sense, since they feed on sulfur and iron. On other planets such "abnormalities" can be much more intense and common. However, we can develop methods and equipment for life detection only based on earth concepts of life.

Though life is theoretically possible on any of the planets, on their satellites, and on the asteroids, our capabilities of launching spacecraft are thus far limited to the moon, Mars, and Venus.

Most scientists believe the moon to be absolutely "dead". However, some forms of life can exist in the shadows of craters, especially if, as shown by recent observations, volcanic activity still occurs there with the evolution of heat, gases, and water vapor. The moon may have already been infected with earth life after the arrival of spacecraft on it, and possibly also by meteorites if they were transporters of life.

Venus also evidently is lifeless, but for other reasons. According to measurements, temperatures at the surface of Venus are too high in order for life of the earth type to be possible there, and its atmosphere is also extremely inhospitable.

Mars is another matter. Its climate and atmosphere are remotely analogous to earth's. Mars is free of contamination by compounds of earth origin. Therefore, the detection of extra-terrestrial life on it is the most probable.

After rocket flights near Mars, as the result of which long-range reconnaissance will be carried out, the time will come to land on the surface of the planet. It can be hoped that the

Martian atmosphere will prove to be sufficiently dense and that a soft landing of a capsule with a parachute can be achieved. But if, as some calculations show, the gravity field on Mars is only 1/40-th of earth's, then an additional jet deceleration device will be required for a soft landing.

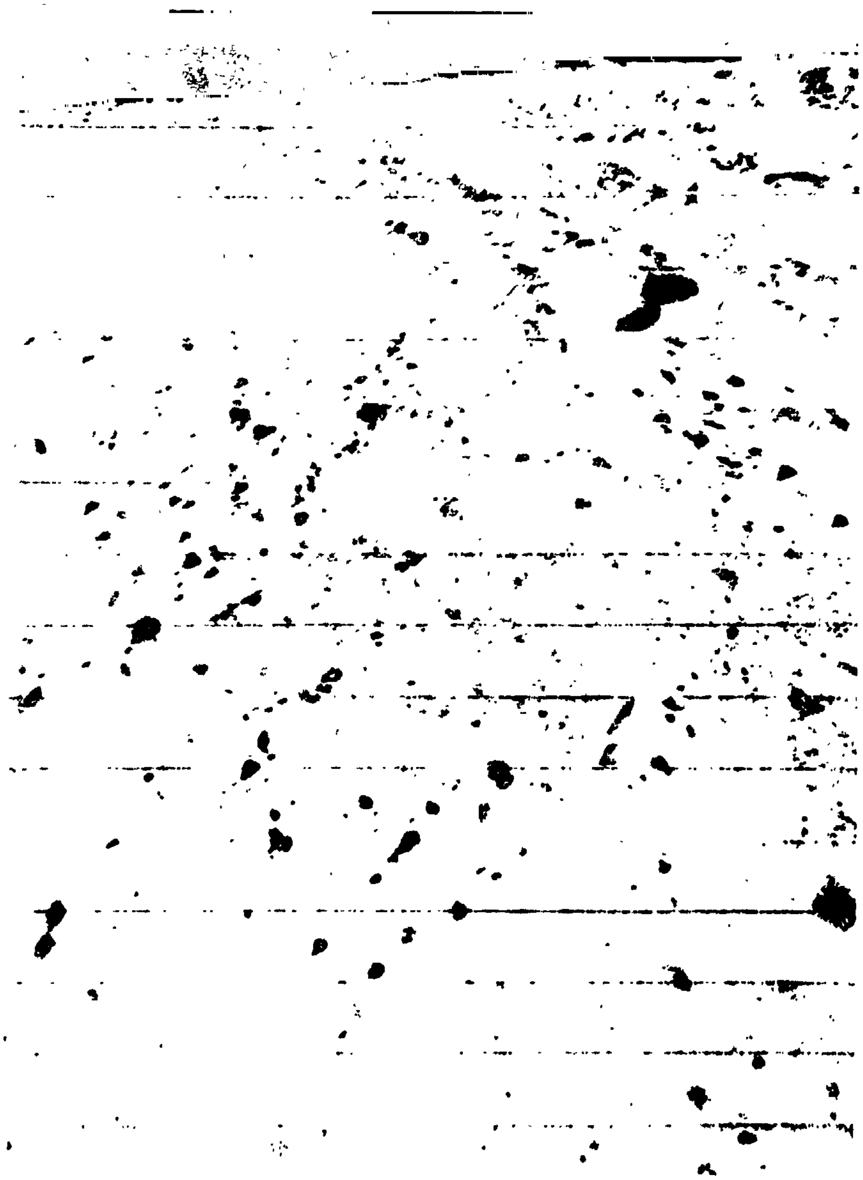
However, braking rockets will create a number of additional difficulties. First of all, they will add to the weight of the unit precisely in an area where the impact is especially intense during landing. Moreover, their control is quite complex, which reduces their reliability. Finally, and this possibly is the most important, they will make life detection difficult. As exhaust rocket gases are released in the area of the landing, organisms existing there may be destroyed.

There also arises a problem related to the number and size of instruments that must be brought to the surface of Mars: must /252 there be numerous small instruments in order to ensure the reliable functioning of some of them and to achieve the statistical reliability of the answers providing limited information? or should we take a risk and try to land a single large spacecraft in an ideal location and in an ideal attitude in order to get the clearest possible information from this location? Both points of view have their advocates.

How far should we go in attempts to detect life in space? If we attempted to do this, for example, in the Mojave Desert (California), then we would try to trap insects or rabbits living there. A much simpler experiment, with much greater chance of success, would be an attempt to detect microorganisms that permeate our entire biosphere. Microorganisms are very resistant, they are easily brought back, it is convenient to work with them, and they multiply rapidly. Therefore even in a Mars landing we must first of all use instruments to search for microorganisms. Martian microorganisms must have a similarity to terrestrial, if we assume that the chemical foundation of all life is similar to the terrestrial.

After landing life detection instruments, we must take samples for investigation. Instrument designers assume that on the surface of Mars or near it there will be dust and other soft substances in which microorganisms are contained, just as on earth. Two methods of collecting this dust-like medium have been proposed: the use of sticky tentacles and pneumatic collectors, which suck up fine particles from the surface or suck in an aerosol from the atmosphere like vacuum cleaners.

Collecting samples! At first glance this appears to be a simple matter. However, each method requires the successful per-



A region of the lunar surface

formance of several uncomplicated, but quite reliable mechanical operations. Let us assume that after millions of dollars have been spent to place a payload of 225 kg on Mars, the motor firing out the tentacles, or the pneumatic valve, breaks down.

The tentacles themselves can break. And, finally, what should we do if the capsule lands on bare rock devoid of dust, or upside-down on a crevasse?

In a table below we describe instruments for life detection, whose basis are physical principles or chemical properties.

Life on Mars, just as life on our earth, probably consists of an ocean of complex chemicals. The detection of macromolecules like nucleic acids, proteins, and enzymes, of course will enable us to suggest the existence of life similar to the terrestrial kind, with high confidence. But, even though this is a weighty proof, we cannot state with complete assurance that there is life on Mars. There is a qualitative difference between the concepts "life" and "prelife" ("protolife"), since the latter belongs in the category of purely chemical states.

Mass spectrometers and gas chromatographs, fundamental chemical instruments for the proposed investigations, can deal only with compounds in a gaseous state. In practice this means that a sample must be heated until its macromolecules break down into the simplest elements. However, the gas chromatograph of the Surveyor rocket was able to detect dozens of relatively complicated chemicals such as acetaldehyde and propionaldehyde. Mass- /255
spectrometers developed by the Massachusetts Institute of Technology for Mars are capable of determining amino acid chains of any molecular weight. Such data from the surface of Mars will be extremely useful.

Nearly all earth molecules produced biologically show optical activity -- the ability in solution form to rotate the plane of polarized light. For example, amino acids usually rotate light to the left, and they are called levorotatory. This ability of molecules associated with life can supply a positive answer to the question of whether there is life on Mars, or, at least, whether it was there earlier.

Mixtures consisting of equal parts of dextrorotatory and levorotatory compounds can be produced synthetically. These mixtures are called equilibrium mixtures; they do not exhibit optical activity since both forms equalize each other. But if bacteria utilizing the molecules for food are introduced into a mixture, they disturb the equilibrium, by destroying one of its forms, and thus the optical activity of the remaining mixture component appears.

Currently an instrument is being developed -- an ultraviolet detector. It will measure the rotation of a polarized ultraviolet rays passing through a solution of Martian soil.

In spite of the high cost of television scanning of the Martian landscape, during the first landings on the surface of Mars television will be used. A microscope has already been built intended to collect particles on a sticky object slide. A television camera focused through the microscope onto dirt and aerosol ensures the reproducibility of the test materials. From these images one can determine particle size, symmetry, optical properties, and reactions to biological dyes.

Already one of the instruments intended for life detection is the Wolf trap, named after its inventor.* The trap records two properties of liquid cultures containing multiplying microorganisms: a rise in turbidity and a decrease in acidity, occurring owing to the accumulation of metabolic products. Turbidity can be measured with a photocell, and acidity -- with an ordinary pH-meter with glass electrodes. One difficulty of using these /256
life detectors is that metabolic processes on Mars can be slower than on earth. Therefore, one must allow for the possibility of conducting quite protracted operations and the link to the earth must be maintained during the entire period. Additionally, one more question arises: what niche is most suitable for Martian microorganisms? We do not know this. Therefore we must prepare nutrients that are more suitable for the interaction of organisms with the environment on Mars. These will most likely be organisms absorbing sulfate, nitrate, and carbonate and that carry out fermentation.

Metabolism is one of the universal properties of life that has attracted the attention of life-detection instrument designers. It includes the absorption of food, the discharge of excrementa, and the evolution of heat. Growth is sometimes associated with metabolism, but in no case is it a distinguishing feature of living substances. A life detector called Gulliver after the famous Swift hero, designed to discover unusual forms of life on remote lands, is constructed on the excrementa detection principle.

The instrument carries out three main operations: first of all, collecting samples from living matter; secondly, supplying it with radioactively labeled food; and thirdly, detecting labeled gaseous end products of metabolism. Instead of the pneumatic collector of samples, sticky tentacles are used in Gulliver, which on being attached to bullets are fired from tiny barrels, and then are drawn back. Adhering organisms fall into a nutrient medium labeled with radioisotopes. When the metabolism is present, some of the evolved gases become radioactively labeled. The present

* Translator: Inventor is Wolf Vishniac, USA.

model of Gulliver traps any radioactive carbon dioxide or hydrogen sulfide on a film over a beta-particle counter. If metabolism is occurring in the sample, the counting rate is increased as more and more $C^{14}O_2$ and H_2S^{35} accumulates. There is also a control chamber containing an antimetabolite. A new version of Gulliver will include light and dark cycles in order to detect photosynthesizing microorganisms.

Among the life detectors, Gulliver is one of the best. Its prototypes have been tested successfully in deserts, on mountain peaks, and in deciduous forests, and has been found to be of high sensitivity.

None of the above-described instruments is notable for its versatility. Experiments that can be performed with them are limited. Later-designed Multivators and Minivators, in contrast, provide for setting up several experiments. They are actually miniaturized biological laboratories. The first Multivator design had more than 30 individual chambers for chemical reactions. Later Minivators began to be designed in which the number of chambers was less than ten. With time the Minivators began to be larger, and the Multivators -- smaller.

A thin filtered sample of Martian dust is drawn into each of the chambers with the collector. Chemical and nutrient compounds are placed in the chambers. Another portion of the chemical and nutrient compounds serves as the control. Sensors adapted for various reactions transmit signals to the earth at specific time intervals. /257

One of the life detection methods on which scientists place great hopes is based on finding the enzyme phosphatase or, as it is still called, adenosine triphosphoric acid. This enzyme is found in all living systems and it can be called ubiquitous. On breaking down into phosphoric and adenosine diphosphoric acids, it gives off energy essential for all kinds of metabolism of living matter. Moreover, phosphorus is a catalyst of numerous metabolic reactions, which considerably simplifies the choice of the substrate that must be placed in the instrument chamber.

For example, the chamber in a Multivator will be charged with a substrate containing a fluorescein-fluorescent /sic/ chemical product bound with phosphate ions. This bonding makes the compound nonfluorescing. Upon absorption of the Martian dust sample into the chamber, the phosphatase present in it will promote the dissociation of the bound molecule, the fluorescein will begin to fluoresce, and this reaction will be detected by a photomultiplier.

LIFE DETECTION SYSTEMS

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Instrument	Operating Principles	Evaluation of Results
Radio wave finder	Detect artificial radio signals	Presence of a civilization
Television transmitter	Vidicon camera transmits image of planet and topography	Detection of large forms of life and artificial structures
Microscopes	Lenses enlarge an object; vidicon camera transmits images	Detection of forms of microlife, artificial structures, and fossils
Optical activity detector	Optically active molecules in solution rotate the plane of polarized light	Optical activity in solution possibly is the only kind for molecules associated with life
Experiments with coloration	Certain dyes provide absorption spectra for proteins in visible light; darkened bands are measured with an ordinary spectrometer	Dynamics of spectral intensity permits solving the problem of where the molecules originated
Infrared spectrometer	Infrared emission and reflectivity of a sample depend on its structure	Dynamics of spectral intensity permits solving the problem of where the molecules originated
Ultraviolet spectrometer	Ultraviolet radiation is absorbed selectively by different centers in a molecule	Dynamics of spectral intensity permits solving the problem of where the molecules originated

Instrument	Operating Principle	Evaluation of Results
Mass spectrometer	Possibility of detecting concentrations of different molecules	Dependence of concentration on molecular weight of amino acid fragments gives key to structure
Chromatographs (gas and liquid)	Sorption columns separate constituents of pyrolysis product	Characteristics of constituents permit the determination of structure
Reduction-oxidation potential	Electrodes in a culture cell measure the potential difference when oxidation-reduction reactions are present	Reactions and their potentials may be representative of life processes
Turbidity (Wolf trap)	Photocell can be used in measuring the intensity of cultural solution turbidity	Turbidity dynamics of a medium can means an increase in the number of organisms and thus in their growth
pH meter (Wolf trap)	Using a pH meter containing glass electrodes	Changes in pH with time can indicate the generation of products of metabolism and, therefore, the presence of life
Metabolism detector ("Gullivers")	Sample is provided a radioactively labeled substance as nutrient. Evolution of radioactive CO_2 will be detected with beta-particle detectors	Evolution of CO_2 in cultural liquid indicates the presence of metabolism and, therefore, the presence of life

Instrument	Operating Principle	Evaluation of results
Oxygen metabolism	Radioactively labeled oxygen atoms in salts dissolved in water must be exchanged with oxygen in organisms if enzymes are present. Mass spectrometer can detect newly labeled compounds.	Detection of enzymes will be proof that life exists

Other experiments which can be carried out in the Multivator chambers include experiments with bioluminescence and redox potentials.

Today selection of experiments and equipment for Mars is underway. Instruments described in this article as well as several new instruments can be part of the automatic biological laboratory.

We must do everything to realize the availing potentialitie and, in the expression of the American radio astronomer, Morrison, determine whether life is a miracle or a statistic.

LUNAR MICROCOSMOS /258

N. Pirie, professor (England)

If people have to live on the moon, then arguments in favor of constructing a "lunar microcosmos," though limited, will be simple. Based on calculations, delivering each gram of material to the moon will cost $10. Water can be secured from rocks or permafrost, and rocks contain sufficient bound oxygen that can be extracted electrochemically if the energy is adequate. Whether we can obtain carbon locally is unknown. Possibly bitumen and hydrocarbons can be found on the lunar surface in adequate amounts. But if there are only rocks on the moon and, like earth rocks, in their initial form, contain only 200 grams carbon per one ton, then they can be scarcely utilized for metabolism. Volcanic earth rocks contain 20-50 grams nitrogen per ton, therefore, even on the moon one could scarcely find a source of nitrogen. Phosphorus and sulfur will be there in abundance, but their daily requirements are not high. Other elements of vital importance do not represent a major problem.

The energy needs of a lunar "colonist" are difficult to predict in advance. The basal metabolism rate will remain probably unchanged, and the use of physical labor will be limited. At first glance it appears that walking will take less energy, since gravitational acceleration on the moon is six times less and it will be easier to climb stairs or clamber down mountains. But while walking over a level area man raises his center of gravity and then lets it descend forward. On the moon this descent will occur much more slowly, and constant thrusts, as in running, will be required to reach the necessary velocity. Owing to the lower weight, the force of friction of the soles against the soil will be reduced by a factor of six. Therefore, with unchanged body mass it will be just as inconvenient to move about on the moon as to run on slippery floor. The energy outlay here will be scarcely less than on earth. Therefore as a minimum we must take the energy outlay required on earth in sedentary work; it is 2700 kcal per day, or 130 watts. This requires each day 240 grams carbon and 4.4 grams nitrogen, that is, 70 grams protein, 100 grams fat, and 336 grams carbohydrates (counting only these basic substances).

Most of the nitrogen in food is given off as urea, but 10-20 percent of it is encountered in the form of simple or complex compounds in urine, feces, sweat, in sloughed skin, in hair, and in finger and toenails. One must not forget about these complex end products, since although they are a minor part of the whole, still in a permanent habitat they will accumulate and ultimately ways of removing them will have to be thought up. The fraction of carbon accompanying these nitrogenous products of excretion is very small; most of it is given off as carbon dioxide. The /260 problem could be solved if carbon dioxide and urea could be converted again into useful compounds.

In photosynthesis, light energy causes a reaction in which energy enters into reserve:

$$CO_2 + H_2O \rightarrow HCOH + O_2.$$

Here HCOH refers to a group of molecules from which sugar, starch, and other carbohydrates are constructed. If we focus our attention on regeneration (trapping and utilization) of 90 percent of the carbon, then we will be limited only by methods of producing sugars and starch, avoiding the more complicated schemes of a closed microcosm. However, plants studied are poorly suited for this simple and narrow utilization. Though many of them -- -- especially wheat and potatoes -- form starch, in these plants starch is accumulated in special organs -- seeds or tubers. But the formation of these organs proceeds slowly and depends on complicated mechanisms controlled by the intensity, quality, and rhythm of illumination. Existing plants evidently will not form grain and tubers during the 14-day periods of light and darkness. Of course, during the lunar night artificial illumination can be used. But given the low efficiency of the photosynthesis process and the low efficiency of producing light, it will probably be more practical to utilize energy for some other method of recycling metabolites. This civilization will most likely be based on utilization of vegetative plant parts, and not the organs of plant reproduction.

Potentially, useful plants can be divided into three groups: one-celled; higher plants, growing in water; and higher plants, growing in soil. One-celled plants, for example, algae, can have the advantage in a spacecraft that they are conveniently pumped through illuminated chambers into a shell . In soil they have no advantages whatever: they are not only less productive than higher plants in the same conditions, but each photosynthetic element in these plants is encased in a shell capable of withstanding all dangers of normal existence, and therefore the end product contains much fiber, which is removed with difficulty. Algae have already gained such broad and undeserved acclaim as a potential food on earth and in space flights that we will not discuss them here.

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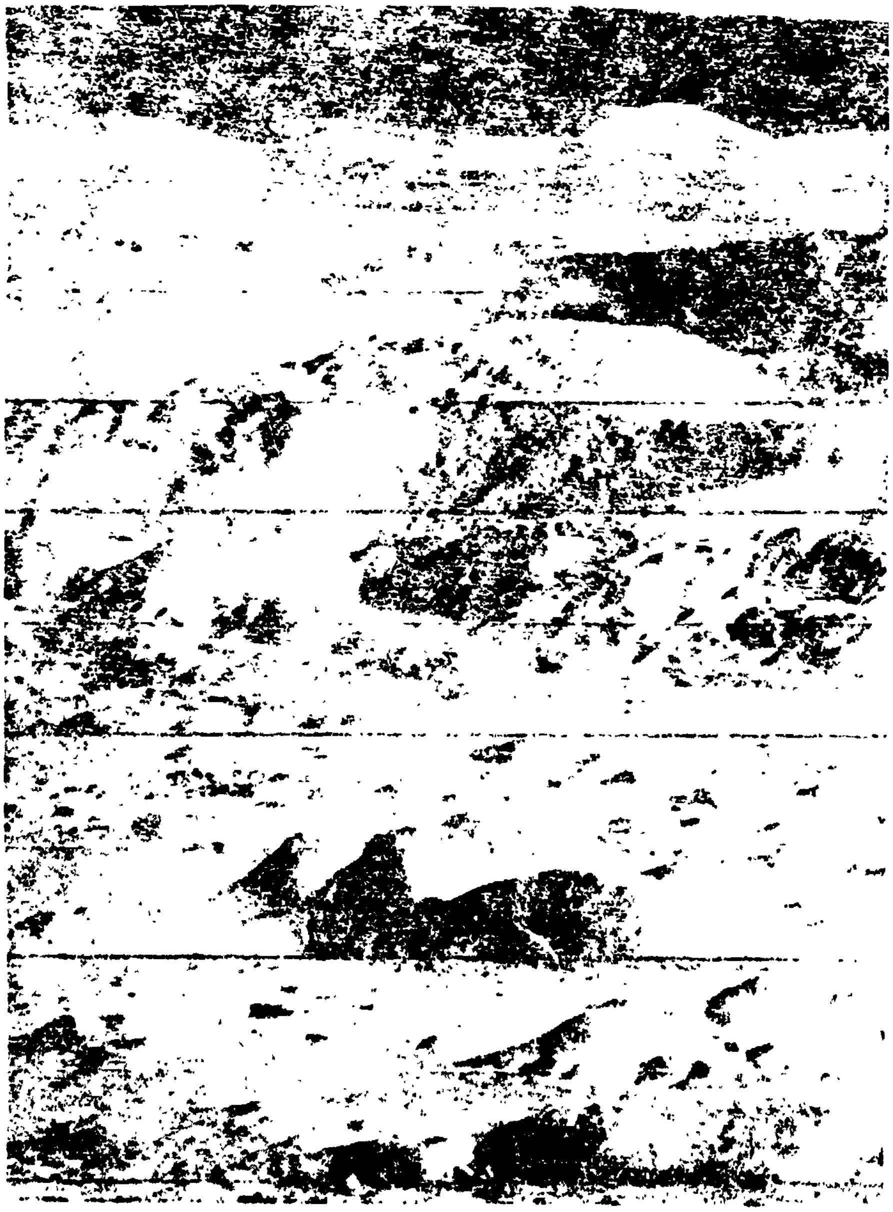

Copernicus crater photographed from an altitude of 250 km by one of the American lunar satellites.

Lunar rocks photographed by the American Surveyor Automatic Lunar Station

Water plants have not become widespread as food, but they may be just as productive as ordinary farm crops. Here we can distinguish two types: fine-leaved with loose structure, and large (for example, water hyacinth). The first is more interesting since it propagates by budding and these plants can be pumped from the tubs where they grow into areas of storage or processing. Plants growing under water or at its surface do not continuously release water vapor into the atmosphere. It is unclear whether this is an advantage. Probably, this will be an advantage in a closed system like a spacecraft, but these plants will need much room and the air surrounding them must be passed through a cold condensation chamber; then their evaporation will be a useful /262
addition to the water distillation system.

The choice between a water crop -- it does not matter whether it needs to be grown in water or whether it only tolerates such conditions -- and a soil crop depends on numerous factors, which are hard to compare with each other. If the moon is completely devoid of life, then there will be nothing like soil on it. But here we can object that the faster we form soil -- whether by grinding rocks, composting, or by other techniques -- the better. On earth ecological interaction with an extremely complex group of microorganisms functions as a "buffer" by suppressing simpler microbial systems. Of course, we do not deliberately plan to introduce tetanus bacilli into our new medium, but if we exclude a few pathogenic groups, then the more massive and more complicated the ecological system, the better it will operate.

Most plants do not tolerate solutions as concentrated as urine. Therefore, cultivation of either a water or a soil crop must begin with a reserve of water to which nitrogenous excretions are added. And since water leaves the soil, whether by evaporation or with the harvested crop, the salt concentration in the soil will rise to the extent that even halophytes will not tolerate it. Therefore, water must be removed from the soil or the tub and desalinized by distillation or electro-osmosis. On the other hand, it may be found that it is better to desalinize urine before using it as a fertilizer; the treated materials here will be smaller, but on the other hand phosphorus and potassium will be lost.

On coming into contact with leaves in which intensive photosynthesis is underway, air may contain only 0.02 percent carbon dioxide instead of the normal 0.03 percent. This is the atmosphere in which nearly all crop yield measurements are made. Experiments in mines, on submarines, and in other locations with limited ventilation show that man can tolerate up to one percent carbon dioxide in the air. Therefore, it can be assumed that the carbon dioxide in the atmosphere of the lunar base may be allowed to rise to this concentration. As for nitrogen, there is no proof that it plays any role whatever in the metabolism of man or plants except for those living in symbiosis with nitrogen-fixating bacteria.

In designing living quarters in the near-vacuum conditions of the moon, any reduction in their internal pressure will be a clear technical advantage. Further, the suction of air from quarters and its loss into the entry air locks will be inevitable. It is scarcely probable that nitrogen can be supplied to the moon only to maintain ordinary environmental conditions. Therefore researchers are busy raising possible lunar crops in gaseous mixtures containing up to five percent carbon dioxide and 95 percent oxygen at a pressure of 100-200 mm Hg. But we have no grounds for assuming that the mechanisms according to which the gaseous mixture will enter through the leaf ostioles will remain unchanged in this modified environment.

If the sun will serve as the source of light for photosynthesis, plants will be exposed to ultraviolet and other components of solar flares, as well as other radiation from which people must be protected. Therefore it is highly probable that personnel will enter plant compartments very rarely or not at all, and their complete tending will be done by remote control. It is also possible that these compartments will be shielded or else that the plants will be removed from them for tending or harvesting. /263

Photosynthetic activity of cultivated plants raised in the temperate zone of the earth falls off with rise in light intensity: the photosynthesis mechanism "becomes saturated." Some plants, for example, corn and sunflower, developing in a well-illuminated environment will effectively utilize even intense light. These conditions depend probably more on the ability of a plant to absorb carbon dioxide and thus to utilize absorbed light than on the light absorption mechanism. If this is the case, then as the carbon dioxide concentration is raised the plants will be eliminated to a large extent; the ability to utilize bright light will be acquired by a larger group of plants.

The temperature at the lunar surface varies from +90° C or higher at noon to -170° at night. The usual "greenhouse effect" within a compartment containing plants will lead to an even greater temperature rise; but even several feet below the surface the temperature will be so low that cooling through circulating water and air through the cold regions will pose few difficulties. And since the sun will shine 300 hours straight and evaporation will be very intense, vigorous air circulation will be needed to remove water vapor.

One of the features of the lunar environment cannot be reproduced at all on earth: the low acceleration due to gravity. Suggestions have been made that this will lead to severe drooping of plants, but here a failure to allow for the usual biological response effects is evident; in an animal bones develop by responding to stress, while wood in the upper part of a bough has a different character than in the lower. Plant growth is strongly regulated by substances such as the auxins and there is evidence that their formation is regulated by the force of gravity. Therefore we must expect that plants on the moon will be more similar to terrestrial plants. Since suitable experiments cannot be conducted on earth, fast-growing representatives of all species must be part of the group of plants selected for lunar testing.

Thus, we can list the factors affecting the selection of a good photosynthesizer on the moon. These must include fast-growing, salt-resistant species capable of utilizing carbon dioxide at concentrations above the usual and illumination -- up to full sunlight; they must also be able to vigorously give off water vapor without wilting in the process.

Thus in the ideal case, all of a plant must be utilized for food. This ideal probably is unattainable. Therefore we will have to select plants with the greatest proportion of edible material or else those from which the largest amount of edible substance can be obtained by using the simplest mechanical methods. As already stated, in the unusual conditions of illumination, the /264 customary grain or tuber will scarcely be the edible portion of a plant. Further, if artificial illumination is not used during the lunar night, the plant must yield a good harvest. This indicates that broad-leaved plants must perforce be used.

Nearly half the organic matter in leaves can probably be isolated in the form suitable for human nutrition. The rest is cellulose, which is fed to cattle on earth, and compounds like sugar, amides, and nucleotides on which microorganisms can be cultivated. If we take appropriate leaves and carefully process them, then less than one-fifth of the proteins remains in the cellulose. A ruminant animal during its full life cycle supplies man with about one-fifth of this amount. Thus, in a cycle involving a ruminant man obtains back less than 1/25-th of the amount of nitrogen initially absorbed by the plant. The principal metabolic role of a ruminant is in transforming the cellulose carbon into carbon dioxide, and this is achieved much more simply by burning it.

A ruminant animal must be preferred to raising microbes leading either to edible hydrolysate or else to the edible microbial mass. At present we know little about the edibility of roots. Roots which remain inedible probably will also be assimilated by microbes. Perhaps it would even be better to utilize the substrate in raising microbes only partially, and to hydrolyze the rest.

In favorable earth conditions, the rate of increase in dry plant matter is 50 grams per m^2 in a 12-hour illuminated day. This

This means that plants are capable of absorbing about 20 grams carbon dioxide and giving off from 53 to 65 grams oxygen, in spite of the distribution of material in the plant. We do not know whether this growth rate can be attained by any plant capable of being used for human nutrition, whether this rate persists in a 300-hour illuminated day, and whether it rises with increase in the carbon dioxide concentration in the atmosphere. However, it can be assumed that 5-10 m^2 of illuminated surface will be sufficient to absorb the carbon dioxide exhaled by a single individual on the moon during the sunlit period. At dusk and at night carbon dioxide must be absorbed chemically. Whether it will then be regenerated by photosynthesis or electrochemically -- this is a subject for another article.

Many studies must be carried out on earth before we begin the study of plant life in lunar conditions. We must investigate the behavior of numerous plant species in atmospheres of different compositions and with continuous bright illumination; plant behavior when fertilization involves mainly human excrementa; plant suitability as food for man, with or without fractionation; physiological effects when these plants are used as food for periods of months; and technical methods for returning inedible portions back into the cycle.

All these studies will help us in understanding the essentials of plant physiology and some will find early application.

5. INTELLIGENCE, ANSWER!

"...without doubt, observations must be continued along with efforts at cosmic signaling in the hope that we will encounter an Intelligence similar enough to ours that we would recognize its symbols. But this, properly speaking, is only a hope, since the Intelligence that we will discover at some time can differ so greatly from our concepts that we may not even wish to call it Intelligence."
Stanislav Lem

Advances in powerful means of reception and transmission of radio waves opened up the fascinating prospect of radio detection of other intelligent worlds. However, the methodology of the natural sciences and its application, in particular, to the study of astronomical objects and phenomena impose severe restrictions on the possibility of interpreting "strange" phenomena in space as the manifestations of intelligent activity. It is sufficient to recall the discovery of objects such as the pulsars: it is difficult to suggest that someone decided to confidently claim that they were of artificial origin. This approach, on the other hand, would open up an avenue to nonscientific speculations on the subject of the artificial origin of certain complex phenomena, and on the other hand -- it would place an unnecessary ban on discovery and study of new phenomena in astronomy.

Devising special languages for interstellar communications, such as for example, Freudenthal's Lincos, has raised the fundamental question of whether meaningful information can be transmitted via a symbolic code system to a recipient who did not know in advance the meaning of what was being transmitted, and moreover belonged to another civilization. We must always bear in mind that understanding the significance of any symbolic expressions is related not to the contemplative-rational functioning of consciousness, but ultimately to all the practical and social activity of man.

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PROBLEM OF SEARCHING FOR EXTRA-TERRESTRIAL CIVILIZATIONS /266

V. A. Ambartsumyan, Academician

It appears to us that the problem of extra-terrestrial civilizations can be divided into three parts: a) the problem of the existence of extra-terrestrial civilizations from the aspect of astronomical prerequisites for the development of life and a civilization in remote planetary systems; b) the task of detecting extra-terrestrial civilizations and communicating between them, and above all the task of our communication with them; and c) the problem of the language and content of the information that can be transmitted. Here it is obvious that this last problem must be formulated differently, depending on whether we are dealing with one-way or two-way communications. In fact, we must bear in mind that at the large distances, exceeding, let us say, a thousand light years, I no longer speak of communications with other galaxies, in practice we can formulate the question only of one-way communications, which to a large extent limits the possible goals of this communication and the nature of the information transmitted.

Before we analyze the question of whether civilizations exist in remote planetary systems (we are sure that there are no other developed civilizations except for our earth's in our planetary system), we must dwell on the concepts of possible material systems that are carriers of these civilizations.

In our usual concept, a carrier of a civilization can be a society consisting of members more or less similar to each other, each of which is capable of understanding, accumulating, storing, and processing and supplying information. It is also assumed that these members themselves are biological organisms. Communication with extra-terrestrial civilizations is viewed as communication with similar societies.

However, one can also imagine other types of carriers of extra-terrestrial civilization. Preliminary considerations show that we cannot in advance reject the possibility of such carriers being in existence. For example, we can imagine a case when a carrier of an extra-terrestrial civilization will be a single cybernetic system not consisting of autonomous parts. Another example of a carrier not similar to a human society can be a system consisting of a set of autonomous, but strictly specialized cybernetic machines and automata.

We will not continue to fantasize on the possible models of carriers of extra-terrestrial civilizations, but we will note, that of course, biological development evidently can proceed at first only to the formation of systems consisting of individual members, however after the stage of biological development conditions for the emergence of carriers of another kind can appear.

At the present stage of our knowledge, we must take account of the fact that biological development is still the most important condition for the appearance of civilization, independently of the forms which it can subsequently adopt. Therefore the question of astronomical prerequisites for the existence of extra-terrestrial civilizations is above all a question of the range of astronomical conditions in which the emergence of life is possible and subsequent extremely prolonged development leading to the appearance of rational creatures and the attainment of given degrees of civilization. If this range will be determinate, the accumulated data of stellar astronomy can serve as a basis for series statistical calculations on the frequency of encountering favorable systems. True, an important link is missing in these calculations: we do not yet know the general regularities of the construction of planetary systems, since we know the construction only of our planetary system. It is also possible that properties of our planetary system such as approximate coplanarity and the nearly circular nature of planetary orbits, the Bode-Titius law are typical only for the solar system and are not special manifestations of more general principles. /26

Increasing the precision of studying intrinsic motions of the nearest stars by one order of magnitude would significantly improve the state of affairs. But still, with the example of solar system we already know what are the possible diameters of planetary orbits and the dimensions of planets, which is very essential in clarifying the possible conditions around other stars.

What then are the most important astronomical parameters, whose values determine that the prerequisites exist for the appearance of life in a civilization? Of course, here we have in mind life on approximately the same chemical foundation as has been realized on earth.

First of all, in our view these parameters must be regarded as the following: a) the stellar constant, which is an analogy of the solar constant for a given planet and characterizes the flux of energy falling on each unit of planetary surface; b) the color temperature of a star, of enormous importance, since photochemical processes are most essential for the development of life; and c) the lifetime of the star.

Besides these parameters, we must also make allowance for others, which appear less essential, but which may be decisive in specific conditions. These additional parameters include, for example, the inclination of the planet's equator to the plane of the planet's orbit; the planet's period of rotation about its axis; acceleration due to gravity; and the binary status or variability of the star. We can, as an example, assume intense variability will be a factor impeding the normal development of life.

In addition to astronomical parameters, various planetographic and planetochemical characteristics are highly significant. Obviously, a major role must be played by the presence of an atmosphere, its composition, and its thickness. As we know, the sea played a most vital role in the development of life; therefore, the presence or the absence of oceans is also of great importance. Finally, the brokenness of relief, the size of continents, and other factors involving dry land may be significant to the growth of a civilization in its initial stages.

Without sensing any doubts about the multiplicity of cosmic objects where at the present time life and civilization exist, we must ponder more deeply the question of possible changes in the technical level of civilization. Although the age of human civilization, in the broad sense of the word, must be estimated at several millenia, still the modern technical civilization has only a history of two centuries. From the standpoint of our subject area, it is also most essential that concepts of the stellar system, that is, the concepts on which the ideas of the multiplicity of possible civilizations are founded, emerged and developed over the past two centuries. Moreover, the ages of planets may differ one from the other by millions of years. Hence it obviously follows that the actual levels of civilizations may differ by millions of years. From this point of view, it must be considered that earth civilization is in its infancy and that there must be vast differences in the levels of extra-terrestrial civilizations. /268

Therefore, the problem of communicating between extra-terrestrial civilizations is at bottom a problem of communications between civilizations at altogether dissimilar growth levels. Each understands that the level, growth rate, and nature of civilization, beginning at a certain stage, vary sharply even in a single century. It is therefore difficult even to imagine the tremendous changes that can occur in hundreds of thousands and millions of years. The practical problem lies, given that a civilization is in the stage of infancy, in finding the most rational technical solutions and also a language for communicating with civilizations at a vastly higher developmental level.

It would appear that before detecting extra-terrestrial civilizations, work on this problem must boil down to rational planning and rational search for signals that may show a most unexpected character and can be coded in the anticipation of being picked up by a civilization at a much higher level than our infant civilization. Actually, it turns out that the very formulation of the problem of communicating between civilizations gives rise to the need to investigate a good many problems having independent scientific importance. Let us recall, for example, the question of the artificiality of signals and messages.

Since the universe can never be studied to completeness owing to the inexhaustibility of its phenomena and even its regularities, however correct a message from out of the universe that would be picked up by our instruments, a message exhibiting internal regularities (simple or complex), we cannot in principle preclude that it is the result of some natural process unknown to us.

A simple illustration of this assertion is the natural character of the radio signals we picked up from pulsars.

Let us assume, for example, that the following message is picked from up the universe, given over and over:

11 001 001 11 001 001 11 001 001

An optimist can say that the number 11 001 001 provides a description of the value of pi in the binary system, with a precision to the seventh decimal place, and he will insist that these are the call letters from some civilization deciding that the periodic repetition of the value of pi will be readily understood as an artificial signal. The pessimist can easily come up with a simple physical mechanism (for example, a rotating cosmic source of a specially selected type) to account for this phenomenon. Thus, from the recording made, in the absence of extra information, we cannot reach a unique conclusion. More precisely, /269 if the optimist does not present arguments based on some additional information, most scientists will say -- by force of the caution to be expected in these cases -- that probably the pessimist is right.

Suppose, however, that we have periodically repeating messages that are not eight bits in length, as above, but 200 bits. And suppose this message is made up of two parts, each 100 bits in length, which are the value of pi coded by two very simple, but completely different methods, with a precision up to the hundredth binary symbol. Then the assumption that the signals picked up are natural will appear to be extremely improbable to everyone, though it cannot be absolutely excluded. From this example, it follows that one cannot devise any absolute criterion of signal artificiality.

The question of possible criteria characterizing the plausibility of the assumption that a given message is artificial can become the objects of a special study independently of the problem of extra-terrestrial civilizations.

The foregoing applies to detecting call letter signals that must be consciously devised by extra-terrestrial civilizations in order to demonstrate as clearly as possible their artificial nature. As for the deciphering of messages that contain actual news, this is an altogether different problem -- the problem of finding the code. It is not precluded that along with call letters, special signals permitting the nature of the code to be puzzled out would prove useful.

From the last remarks it is clear how interest-charged are the scientific-technical problems of the theory of messages sent to a receiving party who does not know either the language nor our ordinary coding techniques.

MULTIPLICITY OF INHABITED WORLDS AND THE PROBLEM OF SETTING UP CONTACTS AMONG THEM

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The problem formulated in the title above is centuries-old. However, only in our day can it be placed upon a scientific footing.

This is due above all to the exceptional successes achieved in astrophysics, radioastronomy, cybernetics, and biology at the molecular level, and in related sciences in the past one to two decades. The very development of sciences dealing with nature and society has by necessity posed this problem precisely in our day. We must not regard as mere chance the fact that in the past several years more than 150 studies on aspects of this problem have already appeared. Collections of articles are being published and the first conferences are being arranged. There is full reason to state that we are witnesses to the birth of a new science, at the frontier of sciences such as astrophysics, radioastronomy, biology, technology, and ... sociology, a science which has not been given a name, but which has already attracted the most intense interest not only from specialists but from much of the public.

What then are the concrete achievements of science that have made it possible to seriously raise the question of the multiplicity of inhabited worlds in the universe and the types of possible contacts among them?

1. The establishment, with high probability, of the paramount fact that planetary systems are widespread in our galaxy. In addition to even though indirect, but quite convincing arguments related to characteristics of the rotation of stars of various spectral classes about their axes, direct proof has also recently come to light.

The famed American specialist on photographic astrometry, Van de Camp found in 1963 that one of the stars closest to us -- -- the Barnard star -- has an invisible satellite with the smallest known mass. Measurement of the negligibly small fluctuations in the intrinsic motion of this star (equal to 10" per year -- the largest amount of all known motions) led to the conclusion that the mass causing these small fluctuations in the unseen satellite is only 1.5 times greater than the mass of Jupiter, the major semiaxis of a quite eccentric orbit is equal to 4.4 astronomical units, and the period of rotation is 24 years. The Barnard star is a red dwarf of spectral class M5, its radius is one-sixth of the solar radius, and its mass is 0.15 of the solar mass.

An object with a mass only 1.5 times greater than the mass of Jupiter cannot be a self-luminous body. The temperature of its interior is too low -- only several hundreds of thousands of degrees. So the thermonuclear reactions that are the energy source of most stars will most likely not occur there. This cosmic body is nearly certainly a giant planet similar to our Jupiter. /271

The fact that a planet has been found near one of the stars closest to us indicates with great force the enormous distribution of planetary systems in our galaxy, and it is in this that the greatest import of Van de Camp's discovery lies. True, we must remember that the orbit of the giant planet moving around the Barnard star is severely elliptical, while the orbits of nearly all planets in our solar system, including the giant planets Jupiter and Saturn are near-circular. It is unclear whether this difference has qualitative significance.

In any case, the multiplicity of planetary systems in our galaxy appears to be established with a very high degree of probability.

2. Of major importance to the problem on discussion are the recent widely known successes of biology at the molecular level, and of biophysics and biochemistry, which for the first time have lifted the curtain from the secret of the origin and essence of life. Without these successes in the biological and chemical sciences we could not even consider understanding the origin of life on earth and other planets. However, we must emphasize that thus far we have only outlined ways of solving this problem. Ahead there yet remains the problem of the regularity of the emergence of life on earth that must be resolved from the standpoint of science; to do this, we need a clear idea of the pre-geological period of evolution on our planet. This requires elevating the level of planetary cosmogony even to the level of stellar cosmogony, which thus far is not known. We must, it is true, take note that here as well at the present time shifts in viewpoint, associated, for example, with clarifying the decisive role of electromagnetic processes, have been contemplated.

3. The exceptional achievements in radioastronomy in recent years bear decisive importance to the problem of setting up contact with extra-terrestrial civilizations. Here we must emphasize the importance of the technical revolution in radiophysics involved with the invention of quantum radiation amplifiers (masers) and the construction of antenna facilities with large equivalent surface areas. All this led to a surge in the potentialities of radiophysics so great that even in our day it is possible in principle to set up radio communications at distances of several tens of light years. Several hundreds of stars can already be

counted in a sphere with this radius. Increasing the potential range of communications by another order of magnitude will become a quite realistic prospect in the immediate decade ahead, which will correspond to the already quite "substantial" distance of about 100 parsecs. We note that already several hundreds of thousands of stars are estimated to lie within a sphere having this radius.

4. A highly important factor in exploring the problems of setting up contact with extra-terrestrial civilizations will be the advances made in cybernetics. Application of the concept and methods of cybernetics is absolutely necessary in analyzing problems such as research for characteristics of optimal signals and the problem of automata. Even today cybernetics is raising the question of the possibility that there may be life forms (including, intelligent forms) of artificial origin. This last problem will take on altogether exceptional meaning in the future.

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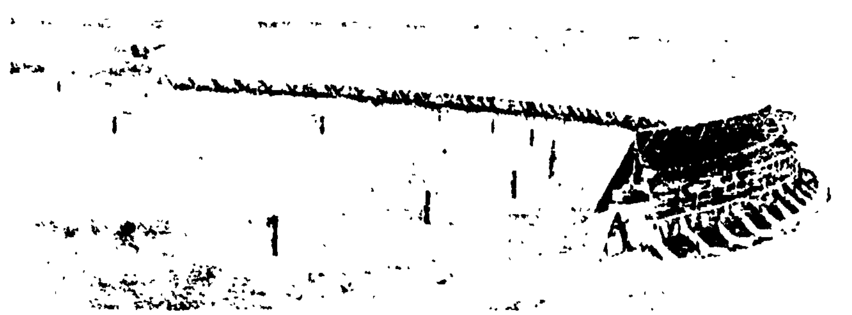


The great Pulkovo radiotelescope.

5. Man's entry into space and the conquest of space represent a most important factor simulating research in the area we are discussing. The irresistible and predictable expansion of mankind into space demonstrates most graphically the capabilities of intelligent life. We can with every reason view this process as a qualitatively new stage in mankind's development. In no other ten years has the scope of man's activity expanded by many thousands of time. But we are witnesses only to the earliest stage of this process and it is difficult even to imagine to what radical changes in the life of human society it will lead when viewed from the perspective of the several centuries just ahead.

The invincible spread of the vigorous, transforming activity of mankind into all of near-solar space inevitably must lead to building an artificial biosphere whose volume will be 10-15 orders of magnitude greater than the natural biosphere. In this respect, I wish to cite one quite well-known writer: "...Incidentally, no one understands the true meaning of the time in which he lives. The old masters painted eating-houses and Saint Sebastians while Columbus discovered the New World before their eyes" (A. Conan Doyle, The Magic Door).

The realistic possibility of finding out whether life is present on the planets nearest to us by direct biological experiment has a most immediate bearing on the problem of interest to us. There is every reason to assume that this problem will be solved in the near future. If, for example, the presence of even the most primitive forms of life on Mars with its extremely harsh conditions will be experimentally proven, this will be actually a confirmation of the concept that life has a higher form of the existence of matter emerges by principle on planets. For there may be billions of planets in our galaxy at suitable distances around stars of spectral types F8-KO, where conditions are more favorable than on Mars. /273

Even if it were shown that primitive life forms on Mars were at one time carried from earth by spores, this would not diminish the importance of our conclusion above. Incidentally, in present-day conditions the problem of panspermia must be formulated anew. The amazing resistance and adaptability of the simplest micro-organisms and their spores to monstrous doses of radiation has been proven. The idea of panspermia has an old philosophical "bugaboo", if of course we do not adhere to the antiscientific view that life has always existed. The universe evolves, and its early stages of evolution exclude the possibility of life. I find absurd the assertion that the "autonomous" emergence of life on planets is a confirmation of materialism, and "pollination" by their spores from space to the idealism. Only scientific arguments and above all experiment and observation can settle this question.

The following question is extremely central: how soon did life on a given planet emerge and travel the complex and long evolutionary pathway, continuously improving, and must it by necessity become intelligent at some stage? I suggest that this is altogether optional. Furthermore, we have to reckon with the possibility that the chance that intelligent life appeared on a given planet is very slight. Finally, there is also the fundamentally important problem of the duration of the era of intelligent life on a given planet (let us denote this by a t). This problem is quite indeterminate. Nearly all foreign workers and many scientists in our country validly suggest that this duration in any case is shorter than the cosmogonic time scale T ($T \sim 10^9$ -- 10^{10} years). It must be emphasized that this is by no means of academic interest for the problem we are considering. We can readily derive, for example, a formula giving the mean distance d between two "contemporary civilizations":

$$d = 5.2\left(\frac{T}{t}\right)^{1/4} \quad \text{parsec.}$$

Although the dependence on t is weak, still if t $\sim 10^5$ -- 10^6 years, then with the most optimistic assumption (the number of planetary systems in our galaxy is of the order of many billions and intelligent life must necessarily appear on each planet) we get that d $\sim$ 100 parsec.

However, we must bear in mind the possibility that some civilizations, on reaching a quite high level of development and overcoming inevitable crises and contradictions can have vastly longer time scales of development, perhaps even close to cosmogonic. Incidentally, I note that the technological stage in the development of a civilization that lasts even 10^5 years is an enormous time- /274 span, which can lead to the most radical consequences.

Now we will sum up the starting data essential for a scientific analysis of the problem of whether contacts can be established among planetary civilizations. In the most favorable case, distances between civilizations are of the order of interstellar distances, that is, 3-5 parsec. This, however, is extremely improbable, for in this estimate we do not take account of an enormous number of factors. Finally, the negative results of recent observations in Project "Ozma" contradict this optimistic estimate.

The minimum mean distance to the nearest alien planetary civilization must be most likely about 300 parsec. This follows from the following assumptions:

all stars of spectral classes F8-KO have planetary systems, and at least one planet in the system is suitable for the development of life, which inevitably emerges on it;

the product α (t/T) $\sim 10^{-5}$ (where α is the probability that life, on evolving, becomes intelligent, t is the duration of the Psychozoic Era, and T is the age of the star). However, we must reckon with the possibility that d can be much larger than 300 parsec, and it is by no means precluded that our civilization is the only one in our galaxy, but of course not the only one in the universe.

As soon as the assertion that we are not alone in the universe appears to be quite well substantiated, we are faced with the problem of the possibility of setting up contacts among civilizations.

The following types of contacts are conceivable:

interstellar flights, in particular the launching of automatic cybernetic probes; and
signals of electromagnetic radiation.

Evidently, the first method (at least for establishing contacts) is not promising. This does not even take into account the fact that it is inaccessible to present-day technology, and has no future.

In conflict with the view of science fiction writers, interstellar photonic rockets traveling at relativistic velocities, most probably will never be built. Each age has a habit of overestimating its technological capabilities. Let us recall in this respect that in the 19th century serious discussion was given to projects of flights to the moon using a ... steam engine. Even earlier some science fiction writers hoped to make this trip -- on a balloon. In our day we plainly overestimate the capabilities of jet technology. This technology is ideal for flights over interplanetary distances and for the future transformation of near-solar space. Moreover, rockets can be a powerful means of gradual expansion of civilization from one planetary system to another in close proximity. In the latter case, however, rocket travel will occur at nonrelativistic velocities. But as a means of setting up contacts between civilizations separated by interstellar distances, even photonic rockets are unsuitable.

Since this is the case, we must look for other possibilities.

The idea of establishing contacts by organizing channels of communications using electromagnetic waves was first advanced by Cocconi and Morrison in 1960. Their work, strictly speaking, also served as a stimulus for all subsequent research in this field. Analysis showed that waves in the radio range are the most expedient, economical, and promising. Within the limits of this range, the range of centimeter and short decimeter waves are most useful. Cocconi and Morrison began with the possibility of communicating in the 21 cm wave length. Soon Drake attempted to detect signals of artificial origin from the nearest suitable stars Epsilon Eridani and Tau Ceti (the "Ozma" Project). However, it appears to us that the "Ozma" Project was faulty in its basis for two reasons. /275

It was assumed that civilizations may be present in the vicinity of the nearest stars, which is extremely improbable. Even if $d \backsim 100$-300 parsecs, the communications problem by means of directed beam becomes extremely difficult, for at least 10^5 stars are within this distance.

In our view, the fundamental defect of the Cocconi-Morrison concept and its realization by Drake was their assumption that the level of the technological development of extra-terrestrial civilizations is approximately the same as ours. Therefore, it was assumed that the power of receivers and transmitters used by extra-terrestrial civilizations is approximately the same as on earth. But this assumption is fundamentally incorrect. It is widely known that the scale of time for the technological development of the civilization is exceptionally short. Therefore, if there are civilizations in the universe, the levels of their development must be extremely dissimilar. The vast majority of civilizations must have a level of technological development incomparably higher than ours. For we are still infants in technology and science. It has not yet been 70 years, for example, since the discovery that radio communication was possible. And not even 30 years have elapsed since the discovery of nuclear energy. We have not yet mastered thermonuclear synthesis.

Therefore, in analyzing the problem of setting up contacts between civilizations, we must even at the "zero approximation" take into account the extremely high level of technological development of alien-planetary civilizations. This consideration is dictated by the practical requirements, for the technical aspect of carrying out the project is determined by our starting assumptions. The only method of estimating the technical level of extra-terrestrial civilizations is to analyze the capabilities of the technological development of our civilization. This is not an easy task, and most importantly it is indeterminate. However, apart from this analysis progress is impossible. To some extent the problem becomes simplified by the fact that it is meaningless to fill in any details of the situation. It is vital to estimate the rates and scales of the activity of a civilization.

The exceptionally short time scale for the development of technology is of decisive importance. It is useful to recall that science and technology in the modern sense of this word emerged only ten generations ago. Galileo laid the foundations of mechanics, and this of course served as the start of its development. And today, only 350 years later, technology has become a factor of cosmic importance, for its capabilities even at the present have outstepped the modest scale of our globe. I will bring up only two examples.

In principle, television on earth in meter wave lengths radiates into space approximately one w/Hz (on earth there are several thousands of television transmitters with a mean signal strength of 20 kw). The brightness temperature of the earth in the meter wave length is about 10^8 degrees. In strength of radio emission in the meter band, the earth is the second body in the solar system, after the sun. The strength of its radiation is 10^6 times greater than for Venus or Mars. /276

High-altitude nuclear explosions have completely distorted the most important cosmic characteristic of the earth, radiation belts. This change possibly will not "be dissipated" and evidently will persist.

In far from every case is mankind aware of the consequences of its activity. I wish to direct our attention at yet another aspect of mankind's activity, which can be of decisive importance for the problems of interest to us. I am speaking about the production of energy and the swift rates of its increase. At the present time mankind produces approximately $3 \cdot 10^{19}$ erg/sec. Presently energy production doubles every 20 years. This trend is quite stable. With time the rates of energy production will rise. At these rates, in 200 years energy production will reach a level of $3 \cdot 10^{22}$ erg/sec, or approximately 1 percent of the flux of solar energy reaching the earth. Considering the rate of increase in energy production, this can occur even sooner. A further increase in energy production will entail changes in the thermal regime of the earth. Of course, before then the wide utilization of solar energy will begin, but here there is a limit -- most likely 10 percent of the entire flux will be utilized. In any case, in less than 300 years the question will become extremely acute. Some foreign authors believe that we will have to most stringently ban the further development of energetics and stabilize it. However, this is scarcely possible. Most likely, powerful energy systems will be transported into space and here mankind will gain enormous (even though still restricted) growth capabilities.

The process of transporting powerful installations into space will inevitably begin much sooner owing to the high radiation hazard that locating such facilities on earth poses, and also due to the necessity of setting up experiments and organizing new kinds of production that require large areas. Typically, even today bold, but quite realistic, plans for important experiments using space bases are being advanced (for example, the Kardashov-Slysh project of installing a radio interferometer on an artificial satellite of the moon). It is precisely for these reasons that pioneering studies of space and the entrance of man into space are of universal-historic significance.

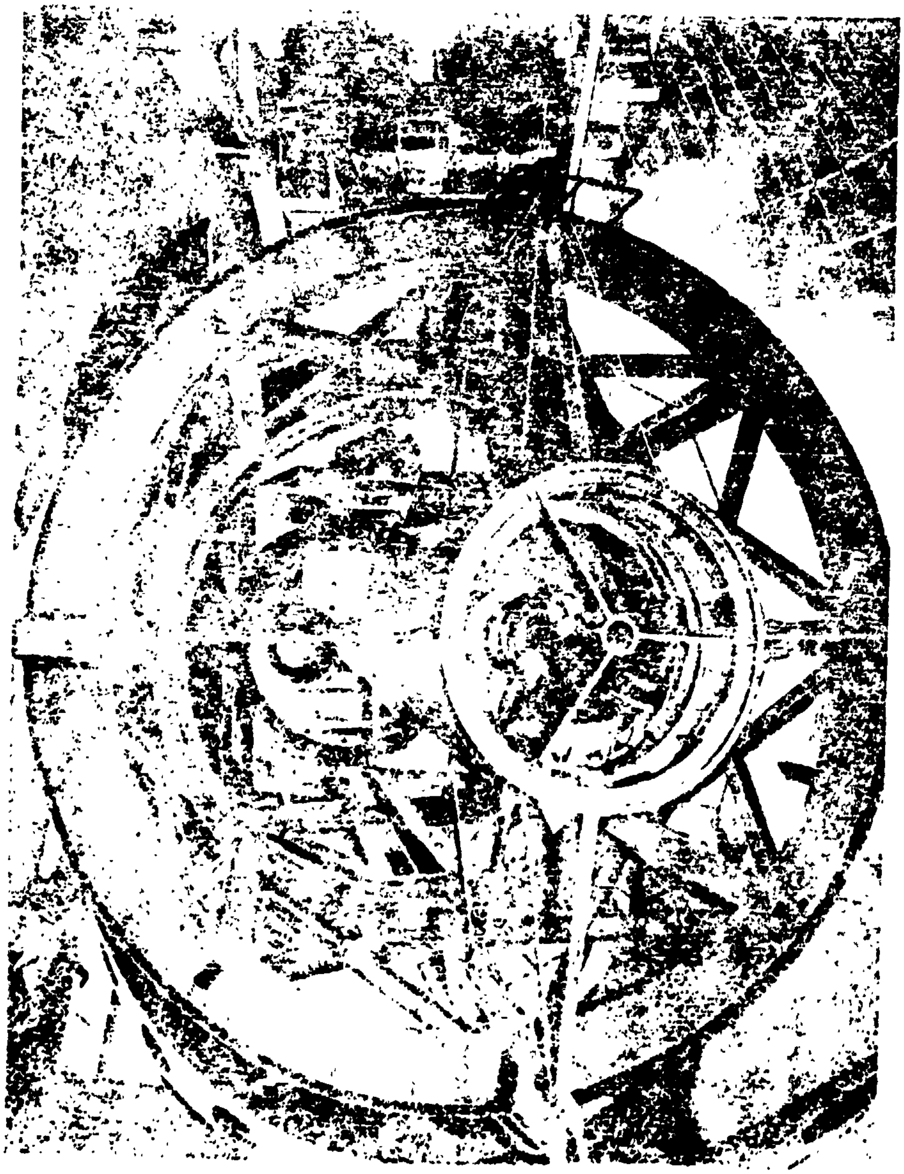
As soon as mankind inevitably begins to master and transform the solar system, his energy and material resources will increase incomparably. The value of 10^{33} erg/sec is not a limit, since part of the mass of the planets can be utilized as fuel for thermonuclear reactions of synthesis. Based on various criteria, we can consider that the time scale for the mastery and transformation by mankind of the solar system is of the order of several thousands /278 of years, in any case less than 10^4 years, that is, negligibly small compared with cosmic scales. Hence there follows a most important conclusion: if there are civilizations in our galaxy, then very many, if not most, have reached a level of technological development which is characterized by mastery of the generation of energy at about 10^{33} erg/sec and the substantial transformation of "their" planetary systems. The linear dimensions of the artificial biosphere within the limits 10^{13} -- 10^{15} cm are altogether possible. We here do not refer to any specific plans for restructuring planetary systems which are already in existence, for example, the Dyson sphere, since our concern is not here. Only the estimate of the potential energy capabilites of this "super civilization" is important.

But can we limit the development and propagation of intelligent life only to a given planetary system? I believe that we cannot. Neither can there be limitations on the capabilities of the highly organized form of the existence of matter which life is.

In principle, the following situation, for example, is possible. On mastering its planetary system, a highly developed civilization begins the process of "diffusion" to neighboring stars. It is even not necessary that they have their own planetary systems. In fact intelligent creatures have quite completely mastered the techniques of building artificial biospheres. Transformation of the neighborhood of an adjoining star can take several thousands of years. Transporting material there will take severl hundreds of years, that is, a time less than is required to transform a neighboring star. The neighboring star "organized" in this way will in turn become a center of diffusion. It can be anticipated that this diffusional process following a single plan will encompass our entire galaxy in several tens of millions of years. Most likely this will take place even faster, for the development of this super civilization will proceed not only quantitatively, but also qualitatively.

Realization of this project will permit raising the level of energy generation to 10^{43} erg/sec or even higher. An essential point is the fact that we do not see the reasons why the progress of civilization has not proceeded thusly in several galaxies. Hence follows the second conclusion: civilizations are conceivable which have mastered the production of energy at a level of 10^{43} erg/year and have built an artificial biosphere in the scale of a stellar system, that is, within the limits 10^{22} -- 10^{23} cm.

We are far from stating that the above-described picture is the inevitable path along which any civilization will develop. We must clearly understand that profound crises await a developing civilization along this pathway. And it is very probable that any of them will prove fatal. We can indicate several such possible contradiction-crises that are foreseeable even today:



The largest five-meter reflector (Mount Palomar Observatory, United States) self-annihilation resulting from a thermonuclear catastrophe or in general a discovery that can lead to unforeseen and uncontrollable consequences;

genetic hazard (that is, the hazard of degeneration);

overproduction of information;

restricted capacity of the brains of individuals, which can lead to excessive specialization. This situation is also fraught /219 with a chance of degeneration; and

a crisis associated with the appearance of artificial inteligent creatures.

Even other types of crises and contradictions of whose existence today we do not even suspect are possible.

Finally, society need not necessarily follow the pathway of "quantitative" expansion. By conserving the level of energetics and forbidding the entry (uncontrolled) into space, a civilization can follow some pathway of "qualitative self-improvement," and entirely new interests will appear. From my point of view, this situation is equivalent to degeneration. But let us assume that this is not so. In this case, I suggest that no one still can be able to state this "loss of interest" is the only possible type of development.

The problems we have been discussing are not so academic as may appear at first glance. The possibility that there are super civilizations with energetics within the limits 10^{33} and even 10^{43} erg/sec is of decisive importance to the problem of establishing radio contacts, as has been shown in studies by N. S. Kardashov.

Yet one more question remains to be discussed: will not such super civilizations in general send radio signals in order to establish contact? This question is rhetorical to a large extent. First of all we must bear in mind that for a super civilization our own civilization and others like it at the embryonic level are of enormous interest. In fact not only it is a primitive society, but even societies of ants, bees, etc. are of interest even to ourselves. Of no less interest and importance to us are the details of the structure and organization of the simplest microorganisms.

Radio communications developed quite recently. A further question arises: will not radio communications play a certain role even in the future. Most likely, yes, if our ideas of nature and its main regularities are valid. For it has been shown that of all the conceivable types of communication, radio communication is the most economical and informative.

Finally, we can detect purely objectively, by observation, super civilizations very distant from us because the objects associated with them do not obey the correlations of inanimate matter or else lead to characteristics that are amazing or even unnatural. We have arrived at the problem of the "cosmic miracle" -- the manifestation on a cosmic scale of activity by intelligent creatures.

This is the situation relating to the problem of extraterrestrial civilizations and the possibilities of setting up contacts with them. It must be stressed that experiments and observations rationally and systematically carried out now will have the final say.

RADIO COMMUNICATIONS WITH EXTRA-TERRESTRIAL CIVILIZATIONS /280

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Within the bounds of our galaxy, radio communications with extra-terrestrial civilizations is possible only at the present level of technology. Let us show this with an example. Suppose the effective area of our receiving antenna will be 10,000 m^2; its noise temperature is 30° K; the wave length is 0.1 m; the stability of the receiver heterodyne frequency and the compensation of the variable Doppler frequency shift occurring due to the movement of the earth is better than 10^{-10}. These parameters can be achieved with present-day earth equipment now in use.

Suppose an extra-terrestrial civilization has a facility with the following parameters for sending signals to us: effective antenna area (or total of areas of simultaneously operating antennas) 100,000 m^2; mean intensity of transmitter 10^9 w; stability of frequency and compensation for variable Doppler frequency shift due transmitter movement is better than 10^{-10}. The transmitting facility with these parameters (if the required means are allocated) could have been developed and built over a period of several years using our technology. Considering the fact that the age of several extra-terrestrial civilizations can be much greater than the earth's, the feasibility of this undertaking must not raise doubts.

Suppose orthogonal signals are used for communications, let us say, long pulse trains of sinusoidal vibrations, whose frequencies determine the transmitted information. Assuming a frequency stability better than 10^{-10}, these frequencies can be 0.3 Hz apart. In this case when transmission is made over a distance of 100,000 light years (the diameter of our galaxy) and if a frequency band is used corresponding to 10 percent of the mean frequency, communications at the rate of one bit of information every 40 seconds is possible with this equipment. When the distance is reduced, the possible rate of information transmission will rise rapidly: for example, at a distance of 10,000 light years using the same equipment, owing to the reduction in the time needed to accumulate the energy from the signal, the rate of information transmission can now be about 10 bits per second. At a distance of 200 light years, the rate of transmission can be about 10,000 bits per second.

For this transmission to be achieved, the antenna of the extra-terrestrial civilization must be aimed at the earth, and the earth's antenna must be aimed at the extra-terrestrial civilization.

The probability of the chance alignment of these directions is extremely remote, since given the assumed high effective antenna areas (this is necessary in order to obtain a sufficient signal energy at the receiver), their radiation patterns will prove to /281 be very narrow. Actually, the principal beam of the antenna will have a solid angle

$$\psi = \frac{\lambda^2}{S} \quad \text{steradians,}$$

where S is the effective antenna area and λ is the wavelength.

For the transmitting antenna selected, we get

$$\psi_1 = \frac{(0.1)^2}{10^5} = 10^{-7}$$

For the receiving antenna, we get

$$\psi_2 = \frac{(0.1)^2}{10^4} = 10^{-6}$$

Thus, the probability of a chance alignment of directions will be

$$p = \left(\frac{\psi_1}{4\pi}\right)\left(\frac{\psi_2}{4\pi}\right) = 6\cdot 10^{-16}$$

If we each seek out the other by the trial and error method, spending let us say three seconds in each measurement, to find the civilization would require the time τ/p, or more than 10^8 years. (Three seconds is the coherent storage time for a frequency stability of 10^{-10} and wavelength 0.1 m. At this time and with the above-adopted equipment parameters, one could more or less reliably pick up a signal at a distance of 10,000 light years. This time must be greatly increased for distances of 100,000 light years.)

Thus, the main difficulty for setting up communications is to find the extra-terrestrial civilization in order to orient our antenna toward it and for it to realize that the earth is ready to receive radio signals and that it should direct its antennas toward us.

Calculation shows that we can detect a civilization at the level of the earth's at interplanetary distances by the emission of all kinds of radio facilities, without sending it special radio signals. But we cannot detect such a civilization even from the nearest star.

Thus, in order for a civilization near some star to be able to be picked up by us in the radio range, it must have operating for some purposes (we do not know for which) radio transmitters much more powerful than those on earth, or else one must send signals specially intended to give knowledge of the civilization.

Let us assume the latter -- suppose an advanced civilization wishing to make itself known sends signals alternately toward all stars at distances up to 200 light years using equipment with the parameters we have assumed above.

If we suppose that each star will be irradiated for three seconds and that in a sphere of radius 200 light years there are about 100,000 stars, the entire cycle will take about four days. In order to detect signals from such a transmitter at a distance of 200 light years with adequate reliability the receiver with the above-adopted parameters would need an antenna with an effective area of 4 m^2. The solid angle from which this antenna would pick up energy is: /282

$$\psi = \frac{\lambda^2}{S} = \frac{(0.1)^2}{4} = 2.5\cdot 10^{-3} \text{ steradians.}$$

In order to cover the entire sphere simultaneously, there must be

$$\frac{4\pi}{2.5\cdot 10^{-3}} \approx 5000$$

such antennas and the same number of receivers. If we examine the heavens in turn, aiming at detecting the above-assumed transmitter in about one year, then 50 such antennas with their receivers would be needed.

Thus, even if only one of 10^5 stars had an advanced civilization wishing to reveal itself, this task is not a hopeless one.

If an extra-terrestrial civilization irradiates not all 10^5 stars, but only those that are more promising with respect to finding a civilization in the vicinity of the star, including the earth, the search problem can be appreciably simplified. Thus, if 1000 stars will be irradiated, then given the above-adopted parameters the cycle of sweeping these stars will be shorter than an hour and the similar relation will probably be detected in about a year even with a single receiver with the above parameters.

On detecting signals, we naturally will direct our larger radio telescopes appropriately and try to pick up any information.

It can be expected that the discovered civilization will transmit this information toward us, not awaiting confirmation that we are ready to receive it. If it will do this with equipment having the above parameters, then the information from a distance of 200 light years will travel, as we have already said, at a rate of 10,000 bits per second. In this case, for the continuous transmission of information the extra-terrestrial civilization would have had to install quite complicated and energy-intensity equipment for each irradiated star about which the presence of a civilization can be expected. However, if it is satisfied with a slower mean rate of information transmission, then these stars can be irradiated alternately or else each can be irradiated continuously, but at a weaker intensity.

Based on these examples, we can draw the following conclusion. Communications between civilizations within our galaxy at the present level of radio engineering is possible, although civilizations must begin to search for each other to achieve this.

If an extra-terrestrial civilization possessing a technology at our level wishes to make itself known and will transmit special radio signals to do this, then it can be picked up by us at a distance of several hundreds of light years using already existing radio telescopes and specially built radio receivers. If it wishes, this civilization can also send us information without awaiting our answer.

SEARCHING FOR EXTRA-TERRESTRIAL CIVILIZATIONS /283

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Plurality of Inhabited Worlds

The discussion of the problem of searching for extra-terrestrial civilizations most naturally begins with the question of their distribution in the universe. While in the general-theoretical, philosophical plane this problem is of profound worldview import, then it takes on practical significance in the problem of searching for extra-terrestrial civilizations, for on the number of the civilizations depends the mean distance between them, and therefore, the vital technical parameter of the range of communications that must be provided for.

There is no single point of view at the present time about the distribution of intelligent life in the universe. There are two opposite viewpoints. According to one of them, life and intelligence are commonplace phenomena in space, there are numerous inhabited worlds with which mankind can attempt to enter into contact. According to the other point of view, life, and all the more so intelligence, is an extremely rare, exceptional phenomenon in the universe so that our civilization more properly exists only as a "sole example."

Arguments in favor of the broad distribution of life basically boil down to the following. At the present time astronomical observations cover a realm of space having a radius of several billions of light years in which there are 10^{10} galaxies, or 10^{21} stars. All data from modern astronomy show that within the limits of the surveyable region of the universe the fundamental laws of physics are valid, and the same chemical composition on the average is observed everywhere. Our sun is an ordinary star in an ordinary galaxy. There is not a single astronomical or physicochemical parameter that would single out our solar system among the 10^{21} stars in the region of the universe accessible to observations. It would be most surprising if among this tremendous number of stars life was able to originate and intelligence could develop only in the vicinity of one of them -- a completely unremarkable star -- our sun. To this we can add further that in recent years fairly serious arguments have been obtained indicating the broad distribution of planetary systems. And modern cosmogonic theories, in contrast to catastrophic concepts dominant at the beginning of our century (such as, for example, the well-known hypothesis of Jeans), do not contradict this conclusion. By consistently developing arguments of this kind, we then reach the point of view which states that life and intelligence are ordinary phenomena in the universe. Undoubtedly, there are very weighty grounds for this point of view. Nonetheless, we cannot accept it as substantiated to the degree of the rigor needed in the scientific analysis of the question. /284

Ordinarily the following formula is used in estimating the number of civilizations in the universe:

$$N_c = N q_1 q_2 p_1 p_2 p_3 f(\tau).$$

Here N is the number of stars in some region of the universe, for example, in our galaxy;

N_c is the number of civilizations in this region;

q_1 is the proportion of stars with planetary systems;

q_2 is the proportion of planets having conditions suitable for the origin of life;

p_1 is the probability of the origination of life on a planet with suitable conditions;

p_2 is the probability that intelligence emerges on a given planet during the course of evolution, that is, the possibility of the occurrence of intelligent life.

p_3 is the probability of the formation of a technically advanced civilization possessing, for example, facilities for interstellar communications; and

τ is the lifetime of a technically advanced civilization. If τ is comparable in order of magnitude with the age of stars T, then $f(\tau) \backsim 1$; if $\tau \ll T$, then $f(\tau) = \tau/T \gg 1$.

The appearance of the factor $f(\tau)$ in the formula is related to the fact that we are interested not in all the civilizations that at one time lived in the universe or in our galaxy, but only those that exist in it at the present time and with which contact can be established (for example, the civilizations whose signals at the present moment are reaching the solar system).

Applying this formula to estimate the number of inhabited worlds, we are forced to confine ourselves to the forms of life which, like those familiar to us on earth, need a continuous input of energy and can develop on some suitable planet near other stars. This means a certain tribute to anthropomorphism, since in this approach we remove from consideration a system of the "Black Hole" type of F. Hoyle, and the like. Incidentally, this restriction must be regarded as rational and inevitable, for otherwise we run the risk of leaving positions of more or less well-established fact and knowledge and falling into the realm of entirely unbounded speculation.

Of all the factors appearing in the formula, based on modern knowledge we can estimate only the astronomical factor q_1 with sufficient reliability. These estimates are based on an ana ysis of the distribution of binary and multiple systems, on the presence of invisible satellites of stars and planet-like bodies (such as near the Barnard star), on study of correlations in the rotation of stars of various spectral classes, and on concepts of stellar and planetary cosmogony. According to these estimates, not less than 10 percent and perhaps most of these stars in our galaxy have planetary systems.

Determining q_2 already involves much more serious difficulties. Usually in estimating it, one first of all excludes hot young stars of spectral classes O, B, and A. It is assumed that life can emerge and develop only during the period of the steady-state radiation of a star. In stars of the sun type, this period is about 13 billion years, while in stars of early spectral classes it is of the order of 10^7 years. This evidently is a period of time that is altogether negligible for evolution. Let us recall that on earth the evolution of organic matter from the appearance of the simplest forms of life all the way up to the appearance of man took about two billion years. If such massive stars of the early spectral classes have planets around them on which life could have originated, without reaching a high level it would have inevitably perished during further cataclysms experienced by the star (transformation into a red giant, ejection of its shell, and exposure of the hot core with intense ultraviolet radiation). It must be added that according to present-day cosmogonic concepts, stars of the early spectral classes most likely do not have planetary systems.

In addition to the restrictions associated with the spectral class of a star, there are restrictions on the size of planetary orbits (an orbit must lie within the so-called zone of life determined by the temperature conditions under which the protein form of life familiar to us on earth can function actively), restriction /286 on the size of the planets themselves, their radius and mass, planetary speed of rotation, etc.

Thus, the general scheme for determining q_2 consists of the following. We first establish some "norm of existence" (the norm of active functioning of protein life is adopted as this norm), and then we try to calculate the probability of realizing these "normal" conditions in other parts of the univers. Naturally, the value of q_2 depends on the "norm of existence" adopted. In other words, to estimate q_2 we must know not only which conditions exist on other planets, but also which conditions are necessary for the emergence and development of life. Already this falls into the realm of biology, or more exactly, exobiology. Thus, q_2 by its nature is a mixed astronomical-biological factor.

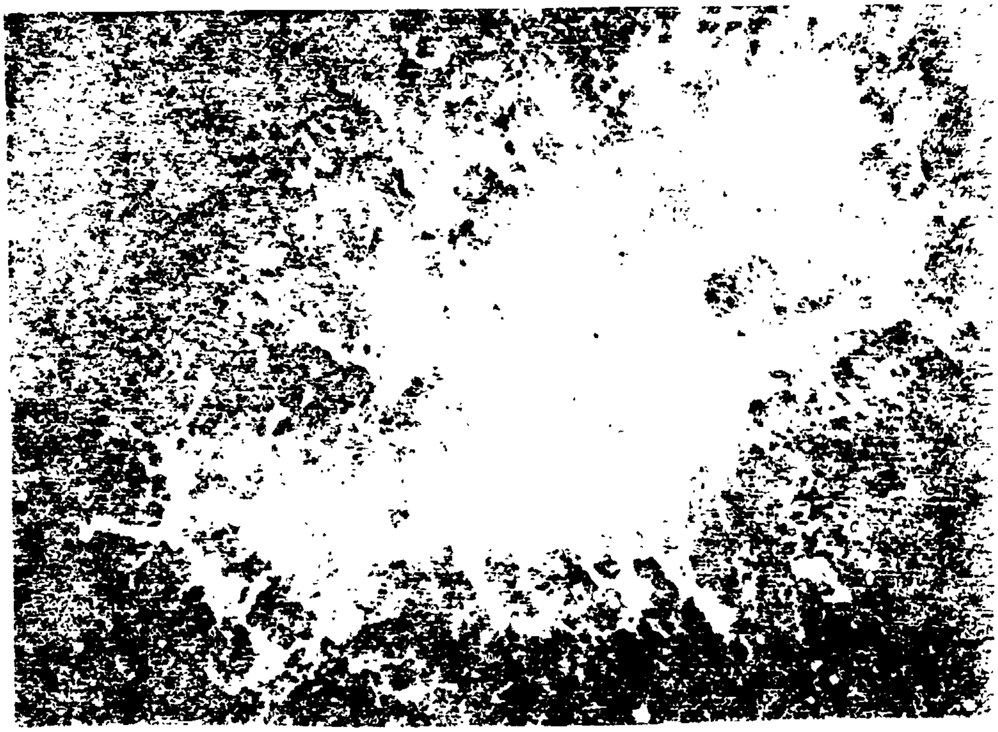
Further thought leads us to the necessity of determining more strictly what is life, what is its essence and specific details, and what are the properties and substrate of life. Discussion still rages over these matters even with respect to the forms of life that are known to us on earth. The problem of the possible nature of extra-terrestrial life remains even more controversial. Often the idea has been expressed of the possible existence of quasiprotein life on a silicon foundation. Recently, as part of the problem of the inhabitability of Jupiter and other planets of this type, several studies have analyzed the possibility of specific forms of life existing in an ammonia environment. The view has been advanced that the chemical foundations of life on other planets can be altogether different.

The possibility of nonprotein forms of life existing expands the range of conditions essential for its emergence, and thereby increases the probability of their realization, that is, ultimately the probability of the emergence of life in the universe. However, the problem of contact with such "exotic" forms of life becomes even more involved, and in particular, so does the problem of exchanging semantic information with the hypothetical nonprotein civilizations. It is not precluded that semantic contact with them is in general impossible.

By the way, not all specialists share the view that nonprotein life can possibly exist. For example, in the opinion of Academician A. N. Nesmeyanov if somewhere in the universe beyond the limits of the earth there is life, it exists there only on a carbon foundation, and more than that -- on a protein foundation. The problem becomes even more complicated if we assume that artificial forms of life can exist. Leaving this question to one side, we note that if we are talking about the naturalness of the emergence of life during the slowly-turning play of the blind forces of nature, then here we must take into account the limitations dictated by the conditions in which this game unfolds -- above all the conditions dominant in the universe. It is precisely from this point of view that Academician V. G. Fesenkov analyzed the question of whether nonprotein life forms are possible; he concluded that life in the universe can be constructed only on the basis of carbon compounds.

Whether or not this is correct, still in determining the value of q_2, as already noted above, we usually start from the only protein form of life known to us on earth. In this case for q_2 we get estimates within the range 10^{-6} to 10^{-1} (depending on the starting assumptions made by various authors). /287

The next factor on which the number of civilizations in the universe depends is the probability p_1 -- the probability that life



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Crab Nebula -- One of the most remarkable objects in the universe.

originated on a planet with suitable conditions. The question as to the value of p_1 is essentially a question of the ratio between chance and regularity during the origination of life, and about to what extent the origination of life can be regarded as a regular process. One very widespread misconception is bound up with this question. There have been attempts to determine p_1 based on calculating the probability of the purely random occurence of thermdynamic fluctuations that must lead to the formation of a complex system, for example, of the protein molecule type or even of a living cell. Allowing for the enormous complexity of this system, we must not be surprised that the probability of this event proves to be vanishingly small. And hence we conclude that life is an extremely infrequent, exceptional phenomenon in the universe (so that our earth was simply "lucky").

The erroneousness of this argument lies in the fact that this purely combinatorial approach is generally not applicable to the process of complicated self-organizing systems. (Based on simple combinatorics of starting elements, it is impossible in a reasonable time to obtain not only a living cell, but even the vastly simpler systems existing in nature.) The point is that during the formation of a complex system, intermediate subsystems are formed at each stage of this process; and due to their intrinsic structural features these subsystems preclude the possibility of the formation of many of the a priori admissible combinations of starting elements. Therefore, at each stage only permitted combinations are realized, which considerably shortens the time and raises the probability of the entire process being realized.

As applied to the problem we are considering (the probability p_1 that life originated on a planet with suitable conditions), we are interested not so much in the ratio between chance and regularity in the origination of life, as much as the problem of whether the realization of this process is stochastic or regular, as a whole. As has been correctly by F. A. Tsitsin, in the abstract this problem lacks any significance. Of course, the emergence of life from nonlife was realized through a mass of chance occurrences, and in this sense (but only in this sense!) the origination of life can be regarded as a random process. For any, even purely random process, there is a characteristic time during which the process inevitably occurs (for experience will repeat itself a sufficient number of times).

During the origination of life, the characteristic time is determined with allowance for the regularity of the formation of complex systems. If it proves to be shorter than the lifetime of the planets, then life inevitably must arise on another planet with suitable conditions. In this case, the origination of life must be regarded as a regular process.

Thus, p_1 is essentially the probability that the following /288
condition will be met:

$$\left\{\begin{array}{l}\text{Characteristic time}\\ \text{for the emergence}\\ \text{of life.}\end{array}\right\} < \left\{\begin{array}{l}\text{Lifetime of}\\ \text{a planet.}\end{array}\right\}$$

Is this condition always met? As we know, it was satisfied on earth. However, the period of the chemical evolution on earth (about 2-3 billion years) is comparable in order of magnitude with the age of the solar system (about 5 billion years) and is nearly of the same order as the age of the universe (about 10^{10} years), that is, the time elapsing from the expansion of the observable part of the universe. The slight difference in physical conditions on other planets (compared with earth conditions) can increase the period of chemical evolution by one-two orders. In this case, more time would be required for the occurrence of life than the age of the universe! Since we know nothing about the periods of chemical evolution on other planets, we cannot say anything definite either about the probability of life occurring on a planet with suitable conditions. However, experiments on simulating the occurrence of life indicate that this time is most likely not too great.

Thus far we have talked about the probability of the spontaneous origination of life. We must however, allow for the possibility of life being transported from one planet to another. Data in recent years indicates that microorganisms are unusually resistant to such factors of space as the highest vacuum, super low temperature, and high doses of ionizing radiation. Ultraviolet radiation is absolutely fatal to earth organisms. However, it is easily screened and therefore microorganisms can persist even on the surfaces of very small particles of cosmic dust. In the internal parts of meteorites living organisms are entirely protected against ionizing radiation and ultraviolet emission. All this compels us to relate seriously to investigating the possibility of life being transported from one planet to another.

Consideration of panspermia (if of course this process is real) leads to an increase in the probability p_1 of life occurring on a planet with suitable conditions. In the most favorable case, we can set $p_1=1$, however there are no grounds to state that this is actually so; we also have no grounds for the opposite assertion, that the probability p_1 is very small.

Even more involved is the question of the probability of the emergence of intelligent life. It is completely unknown how regular is the process of evolution leading to the formation of intelligent life on earth. Many specialists note that with complexity of organisms during the course of evolution, the pathways of evolution become increasingly ramified. Many assume that only some of them lead to the appearance of intelligence. If this is so, then many experiments on different planets had to be arranged by nature before the experiment would be crowned with success on one of them and evolution would have traversed the pathway which led to the appearance of intelligent creatures. Therefore, as has been properly emphasized by I. S. Shklovskiy, even if we assume that /289
the inception of intelligent life in the universe is a regular process of the development of matter, then it does not at all follow from this that the evolution of living matter on each planet must variably lead to the appearance of intelligence.

The opposite conclusion -- that the origination of intelligent life in the course of evolution on each planet is inevitable -- can be obtained on the basis of ideas on biological convergence. A serious argument in favor of this point of view evidently is the origination on life of two types of living creatures possessing highly developed brains (man and cetaceans).

However, there is yet another difficulty: the period of biological evolution on earth (just as the period of chemical evolution) is comparable with the age of the universe, in order of magnitude. Therefore a small deviation of conditions on other planets from the earth "norm" could have led to the evolution of living matter on these planets requiring a much longer time.

And thus, we can set:

$$p_2 = p_{21}p_{22},$$

where p_{21} is the probability that evolution on a given planet follows a pathway leading to the appearance of intelligent creatures; p_{22} is the probability that the time of biological evolution on a given planet (all the way to the appearance of intelligent creatures) is shorter than the lifetime of this planet.

Since we do not know anything either about the probability p_{21} of the time of biological evolution on other planets, p_2 also remains undetermined for us. Study of this problem is of great interest for the question of communications with extra-terrestrial civilizations.

The question of the probability p_3 of a technically advanced civilization forming is also highly involved. In referring to this problem, the American physicist F. Morrison observed: "We are stepping on thin ice of speculation with which our science is unable to cope, since we do not have a reliable theory of the social behavior of complex societies. Our experience, our history are not yet rich enough in order to enable us to make valid general relations." Actually, can we speak about the convergence of the ancient civilizations of India, China, America, and the Middle East? Was the European renaissance and the industrial revolution in Europe that followed it a unique phenomenon in world history or must it inevitably occur in India, China, and on the American continent? Are not the porpoises an example to us of a community of intelligent creatures not utilizing implements of labor and thereby not producing any technology?

Now let us examine one more factor on which the number of civilizations in the universe depends -- the lifetime of technically advance civilizations. There are also two opposite points of view about this value. According to one of them, the lifetime of technically advanced civilizations is limited (of the order of several hundreds, several thousands, or perhaps several millions of years); in any case, it is very short compared to the cosmological time scale. This is the so-called short scale of life. According to the other point of view, the lifetime of technically advanced civilizations is indefinitely great. Once appearing, a civilization develops practically without limit, continually adapting to new conditions (or producing other conditions for itself), overcoming new difficulties, achieving new triumphs in the battle with the "hostile" forces of nature. From this point of view, the lifetime of technically advanced civilizations can be commensurable only with the age of the universe (the long scale of life). /290

Sometimes the suggestion is made of the infinitely long existence of civilizations. Based on the data of cosmology, the present age of a civilization cannot exceed 10^{10} years. So this suggestion can relate only to the future. However, even in this case, that is, as applied to the future, examination of time intervals beyond the limits of the cosmological scale is scarcely meaningful. The present (that is, at the moment a signal is sent) age of civilizations is of interest for the problem of communicating with extra-terrestrial civilizations. Therefore we can speak about the short or long scale of life of civilizations, but it is quite useless (within the limits of our problem) to discuss the probability of the infinite duration of the Psychozoic Era.

The suggestion of the short scale of life of civilizations has often been called pessimistic -- and therefore (!) regarded as invalid. But the hypothesis of the perpetual life of civilizations is regarded as more attractive because of its "optimistic", "life-asserting" character. It is superfluous of course to speak about the categories of optimism and pessimism being related to the objective-emotional sphere and therefore is not being applicable to scientific principles reflecting objects of reality. But even if we use these categories, then evidently we must admit that a life span of 10^{10} years for civilizations is a span of time quite adequate for optimism.

Study of the value of τ falls within the competence of biology and to a greater extent -- sociology. More correctly, we must speak about space biology and space sociology. Here the decisive word must belong precisely to these fields of science.

In the short scale of life of civilizations, the quantity $k = \tau/t_{de}$, where t_{de} is the delay time in interstellar conversations equal to the time required for a signal to be propagated to the recipient and back again plays a key role in the possibilities of exchanging information between civilizations ($t_{de} = 2R/c$, R is the mean distance between civilizations, and c is the speed of light). When $k < 1$, two-way communications between civilizations is impossible; when $k > 1$, two-way communications, in any case in principle, is possible. According to von Horner, effective exchange of information between civilizations can lead to an appreciable increase in their lifetime (the feedback effect). Setting $k = 1$, we can determine some characteristic critical time

$$\tau_0 = \left(\frac{8R_0T}{c^3q_1q_2p_1p_2p_3}\right)^{\frac{1}{4}}$$

(R_0 is the mean time between stars). When $\tau < \tau_0$ the feedback effect is absent, and the lifetime of civilizations remains short. /291

When $\tau > \tau_0$, owing to the feedback effect, the lifetime of civilizations after the establishment of contact begins to rise. Thus, τ is either smaller than τ_0, or else much larger than this quantity. Civilizations whose lifetime is close to τ_0 must be extremely infrequent from this point of view. Of course, all this is valid only if the feedback actually exists, and this is possible only given a condition of semantic contact between civilizations -- a condition that is necessary, but insufficient.

Let us try to sum up. As we can see from the foregoing, in estimating the number of inhabited worlds we must take into account the number of factors whose involvement inevitably leads to formulating such questions as the essentials and specifics of life, the possibility of the existence of nonprotein forms of life, the ratio of chance and regularity in the origination of life, the possibility of panspermia, regularities of biological evolution, and the probability of entelligent forms of life appearing, the probability of the origination of technically advanced civilizations, and their lifetimes. Indeterminacy or the total absence of data on these questions lead to considerable indeterminacy in the estimates of the number of inhabited worlds. It must be admitted that at the present level of knowledge, even a rough estimate of the number of civilizations in the universe is impossible. From the most optimistic estimates (when in particular it is assumed that the probabilities p_1, p_2, and p_3 are of the order of 1), we can expect 10^5 -- 10^6 civilizations in our galaxy. However, if these probabilities are very small (so that the product $p_1p_2p_3f(\tau) < 10^{-21}$), then our civilization proves to be the only one in the universe. Based on the available data, we cannot exclude even this extreme situation, though it appears highly improbable.

Cosmic Miracle

Very often attempts are made to find some determinacy in the question of the number of inhabited worlds by reasoning from the contrary. Let us assume that there are numerous technically advanced civilizations in the universe. Can we detect their presence reflected in some phenomena observed in space? Here we arrive at the concept of the so-called cosmic miracle. By cosmic miracle we mean observation using astronomical methods of the manifestation of activity by intelligent creatures on a cosmic scale (astro-engineering activity). A particular case of the miracle will be an encounter with the expansion of intelligent creatures into space.

We know that the progress of mankind at the present time in all of the most important characteristics (growth of population, growth of energy demands, accumulation of industrial products, accumulation of scientific information, etc.) is proceeding exceptionally rapidly -- exponentially, or even faster than exponentially. Let us assume that these regularities are valid also for other civilizations, and that they are valid for an indefinitely long time interval. Such a civilization will be continually in need of an ever increasing input of matter and energy. Soon, as the resources of the native planet, and even of the entire planetary system, are exhausted, the planet will have no other way out than to steal matter and energy from cosmic space around it. The sphere of activity of this civilization will expand indefinitely. Sooner or later it must inevitably encounter us. Allowing for the inevitable difference in the ages of the civilizations and the achieved rates of mastering space, it can be concluded that this event most likely has already occurred.

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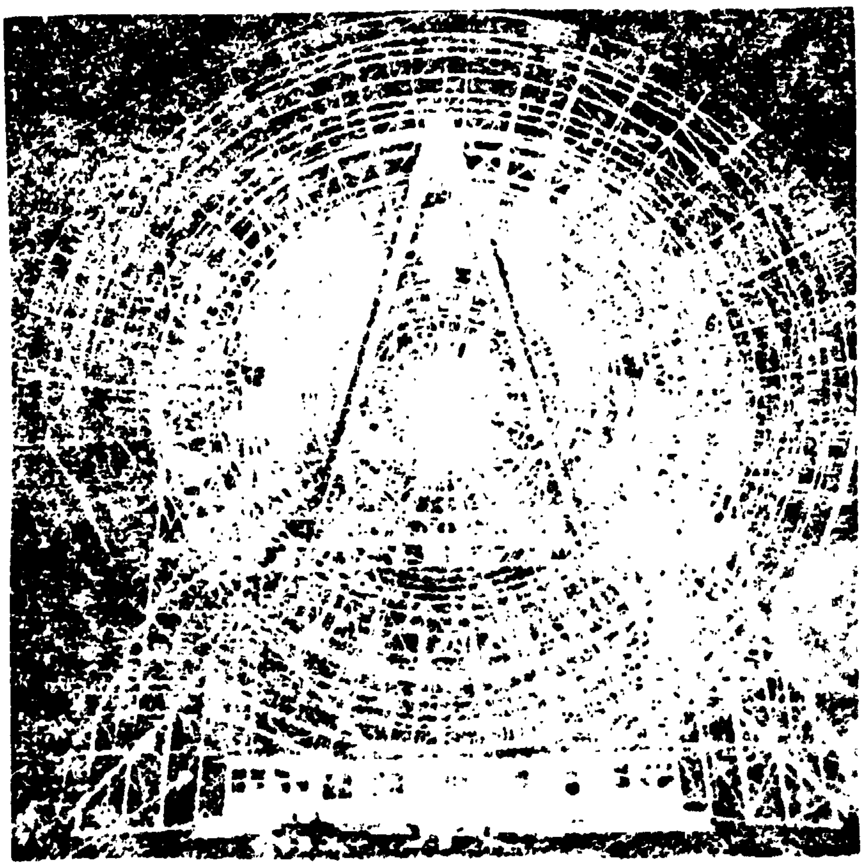

Antenna of one of the powerful radiotelescopes

Let us examine the following speculative example for greater cogency. Assume that in the center of our galaxy there is some civilization which during its growth reached such a high level that interstellar flights became possible for it (at least to the nearest stars). Flights to the nearest stars do not require attaining relativistic speeds so their possibility raises no doubts. Let us suppose that at some moment of time the civilization sent several expeditions to neighboring stars located within a sphere having a radius of 10 light years where -- according to observations -- planetary systems with life-suitable conditions have been detected (a sphere with a radius of 10 light years is selected because within this sphere one can expect several life-suitable planetary systems). On arriving at its destination, the crew of each ship lands on the corresponding planet and begins its colonization. After a certain time has elapsed, let us say, a thousand years (considering the growth rates of mankind, this period can be taken as quite adequate), each colony begins to be sufficiently numerous, develops powerful productive forces, and will be capable itself of sending expeditions to neighboring stars. Suppose the goal of the new expeditions will be planetary systems situated in a sphere having a radius of 20 light years from the initial parent star (more exactly, within the annular layer between spheres with radii of 10 and 20 light years, respectively). On arriving at their destination, each expedition begins to master a new planetary system, and a thousand years later their progeny send out expeditions to new worlds. It turns out that from the center of our galaxy foci of civilization have propagated like spherical waves at the velocity of 10 light years per 1000 years (the "diffusion" of the civilizations is 0.01c). Thus, in several million years the whole galaxy will be mastered by intelligent creatures. Encountering the expansion of these creatures and their transforming activity in space could be one of the example of a cosmic miracle. /293

The absence of a "miracle" associated with the straightforward expansion of intelligent creatures into space will lead to a certain dilemma (let us call it dilemma A): either the lifetime of civilizations is greatly restricted -- short scale of life; or our civilization is the only one in the universe. (In applying this dilemma to the above example of colonization of our galaxy, we would say that: either our civilization is the only one in our galaxy, or the lifetime of civilizations is shorter than several millions of years.)

What position in this dilemma must be given preference? Many authors tend to favor the exclusiveness of the human species, evidently accepting the assumption of the short scale of life of civilizations as being more "criminal". Others (the "optimists") believe both positions are inapplicable and see a way out in adopting yet another logically acceptable, although from the scientific point of view, altogether unsatisfactory possibility, namely: our civilization is not the only one, but it is the most advanced, the most developed in the universe. This point of view is, of course, an extreme manifestation of anthropocentrism.

It must be emphasized that this dilemma (A) is based on the (usually tacit) assumption that the progress of a civilization must necessarily proceed in the direction of completely unbounded /294 quantitative growth (the spatial sphere of activity, energy, mass, and other indicators increase). S. Lem in his Summa Tekhnologiy / Summa Technologica / calls this assumption the orthoevolutionary hypothesis: the future is understood as only an expanded present. This development of civilizations is of course not obligatory. It can be suggested that after a certain time period has elapsed civilizations will enter a state of homeostatic equilibrium, typical of complex systems, with fine regulation of basic processes and the maintenance of vitally important parameters within specified limits.

At least this possibility is not worse than the alternative assumption of the unbounded quantitative growth of civilizations. Still, when we look at the basic dilemma it is completely excluded. It is here that the inexactness of the dilemma lies: the "unboundedness of the progress of intelligence" does not contradict the multiplicity of inhabited worlds if it is assumed that civilizations can develop as completely homeostatic systems. Therefore, this dilemma must be formulated more rigorously as follows. Either we assume that civilizations during an unlimitedly long time interval develop along the pathway of quantitative growth (orthoevolutionary path of development) and then the absence of a miracle associated with the spatial expansion of civilizations means that our civilization is the only one in the universe (or the most advanced (!) of all); or else we assume that the time period of quantitative growth of civilizations is bounded (the short scale of life or the homeostatic path of development), their expansion does not reach such gigantic dimensions, and then simultaneously there may be numerous civilizations in the universe or even in our galaxy (dilemma A').

Usually the problem of the cosmic miracle is handled more broadly (not only as a collision with the spatial expansion of civilizations). Considering that even today the sphere of activity of mankind is not limited to the scale of the globe, but it is increasingly becoming a factor of cosmic importance, the problem will be posed thusly: have not traces of activity by other more developed civilizations been observed in the universe, whose scale of cosmic activity exceeds our modest capabilities? Have not other "miraculous", "supernatural" phenomena been observed in space that could evidence intelligent activity by rational creatures? A negative answer to this question indicating the absence of traces of astro-engineering activity by highly developed civilizations would lead to the same dilemma (A').

Here we must first of all note that in this expanded treatment of the cosmic miracle we have no grounds to assert that there is no miracle. Actually, we could with every reason regard a miracle to be the reception of radio transmission from an extra-terrestrial civilization. This miracle may not have occurred, but can we say that it will not happen tomorrow? In fact, systematic search for radio signals from extra-terrestrial civilizations has not yet been undertaken, and we are only trying to feel our way toward this this problem. Incidentally, even today it is clear that to detect "intelligent" radio signals from space would require setting up special quite complicated radio engineering /295 systems and using special methods of analyzing space radio emission different from the methods that are used in radio astronomy. The same is also true of the possibility of detecting the Dyson sphere near remote stars: modern astronomy lacks data on the basis of which the existence of this phenomenon could be refuted. In general, as for traces of astro-engineering activity by civilizations, the possibility of their detection depends on the energy potential of civilizations. If it is assumed that the potential of civilizations is not boundless, then we have no reason to assert that such miracles do not exist: the results of astro-engineering activity by civilizations cannot be so "luminous" as to be seen directly upon glancing at the sky, even using powerful telescopes. A single miracle, whose absence we can confidently speak about, is the miracle associated with the spatial expansion of civilizations. But, as we have already said, this pathway of progress by civilizations is at the least not the only possible one.

The indeterminacy associated with this entire problem arises because we have no well-defined criteria of the cosmic miracle, we do not know in what it differs from natural-physical processes observed in the universe. So sometimes the suggestion is made that the cosmic miracle has been observed by us: we do see traces of activity by extra-terrestrial civilizations, but failing to understand how they must have come about, we attribute a natural origin to observed phenomena. As an example one is usually given such astronomical objects as quasars, sources of OH emission ("mysterium"), and the famous pulsing radio sources -- pulsars. To the extent that we encounter certain difficulties in explaining these phenomena, this treatment of the miracle formally corresponds to the meaning of this word in Dal's dictionary: "A miracle is any phenomenon that we are not yet able to explain based on laws of nature known to us." However, in the philosophical-methodological plane, this assumption is completely inapplicable. Advances made in explaining all three phenomenon at the present time show this once again.

Thus, our examination of the concept "cosmic miracle," as follows from our discussion, leads to the following alternative possibilities:

1. There are many civilizations, but they are not long-lived (short time scale);
2. Our civilization is the only one in the universe;
3. Our civilization is the most advanced;

   Within the framework of the orthoevolutionary hypothesis (unlimited quantitative growth of civilizations)

4. The nonorthoevolutionary, homeostatic pathway of development (astro-engineering activity is either completely absent or is of a limited kind);
5. There are civilizations, they are numerous, we see them, but we do not realize what we are seeing.

Premises 1, 2, and 3 are valid only within the framework of the orthoevolutionary hypothesis. This hypothesis, as already noted above, is completely unsubstantiated. Therefore, we cannot substantiate based on the cosmic miracle either the premise that our civilization is the only one, nor the premise of the short scale of the life of civilizations, not to speak of the extremely anthropocentric premise 3. Of course, this does not mean that the contrary premises are valid: the multiplicity of inhabited worlds or the longevity of technically advanced civilizations. Actually, the homeostatic path of development indicates the possibility of the prolonged existence of numerous civilizations even in the absence of traces of their astro-engineering activity. However, we do not have any proof that this pathway has been realized in actual fact (although this does appear extremely probable). /296

Thus, involving the concept of the cosmic miracle in estimating the number of inhabited worlds essentially is completely useless: it does not afford us any assistance in estimating the number of inhabited worlds, or in estimating the lifetime of technically advanced civilizations. The problem, as before, remains open. Therefore we are compelled to conclude that the premise that intelligent life exists in the universe beyond the limits of our globe still remains a hypothesis, probable to the highest degree in the face of all modern data, but a hypothesis nonetheless.

Taking this hypothesis as our basis, we can estimate the chances of contacting extra-terrestrial civilizations. This approach corresponds fully to the methods used in science, especially if we consider that today for the first time in the entire history of science, facilities for verifying this hypothesis are available. It would scarcely be correct to require independent proof that extra-terrestrial civilizations exist before we begin their systematic search. It is difficult to agree with the view that this search will be rational only after independent proof is obtained that extra-terrestrial civilizations exist. This would doom us to passivity in waiting for the "miracle", which conflicts with the creative, active spirit of science. It is precisely the search for extra-terrestrial civilizations (and, above all, searching for their signals from outer space) that is the best way of testing the hypothesis that intelligent life exists in the universe, for it is precisely this search that must yield the desired proof confirming or refuting this hypothesis. Of course, the search must be carried out using scientifically sound methodology.

"Game" of Interstellar Communications

A block diagram of the system of interstellar communications can appear as follows. The sender's message goes to the transmitter, where it is transformed into an electrical signal and is emitted into outer space via the transmitting antenna. At the receiving end of the communications line, the interference-distorted signal is picked up by a receiving antenna and is sent to a receiver, where it undergoes various transformations, as the result of which the initial message is restored from the signal obtained, with a degree of reliability.

Properly speaking, this is how any communications system operates. When a system of interstellar communications is set up, one fundamental point of difference will have to be encountered. Ordinary communication systems are designed all as a single entity from the transmitting end to the receiving end and therefore are intercoordinated. /297

The case is otherwise in a system of communications between civilizations. The specific features of constructing interstellar communications lie in the fact that different components of the system are designed by different parties. None of them knows in advance about the actions of the other, and can construct only more or less plausible assumptions, on the basis of which he attempts to coordinate his actions with the actions of his partner. For example, the receiving party can construct certain assumptions about the system of transmission used by the sender, and on the basis of these assumptions adapt certain methods of reception. In turn, the sender must take allowance of the methods of reception which the receiving party will employ, based on his considerations about his (sender's) actions. A typical game situation results. The uniqueness of this fascinating game in interstellar communications in which the rules are established on the basis of objective laws of nature is that the partners, instead of trying to break up intentions one toward the other, attempt to jointly find a solution enabling the game to be played to a finish.

The solution of this problem evidently becomes simplified by the presence of a common element, more properly, an element not belonging to any of the parties, namely the communications line. In the system of interstellar communications the line is the region of space between the transmitting and receiving antennas in which the radio waves are propagated, that is, this is the interstellar, interplanetary medium and planetary atmospheres. Study of line parameters allows certain conclusions to be made about how this system of interstellar communications must be constructed, in particular, conclusions about the optimal wavelength range for communications between different civilizations.

In solving this problem we must base ourselves not on temporary advantages arising due to progress in particular technical facilities in communications, but on some fundamental restrictions inherent in the nature of things and common to any extra-terrestrial civilization.

It is well known that the earth's atmosphere is opaque to nearly all frequencies of electromagnetic radiation, with the exception of two narrow spectral regions: the "optical window" in the interval from 0.3 microns to several microns and the "radio window" from 4-8 mm to 16-30 m. The absorptivity of the atmosphere is determined by its structure and chemical composition. Thus, in the ultraviolet spectral region for wavelengths shorter than 0.3 microns absorption is due to ozone, and in the infrared region -- mainly due to water vapor. In the radio range, for waves shorter than 1 cm, absorption is due to molecules of oxygen and water vapor, and in the decameter spectral region waves are intensely absorbed by the ionosphere.

We do not know the structure and makeup of atmospheres on other planets where there may be highly developed civilizations, just as they do not know the composition of the earth's atmosphere. At first glance this renders the entire problem of selecting wavelength ranges for interstellar communications indeterminate. Fortunately, the restrictions associated with the absorption of electromagnetic waves in planetary atmospheres are not among the fundamental ones. Even for earth civilization, which by the level of its development is undoubtedly a "cosmic infant," the problem of transporting beyond the limits of the atmosphere communication facilities intended for interchange with other civilizations is a technically quite realistic problem. Furthermore, this is valid for any highly developed civilization. Therefore in our game we must be guided precisely by this case, otherwise the rules of the game become indeterminate. /298

These rules compel us, in our theoretical analysis, to cancel out of consideration planetary atmospheres, limiting ourselves to analysis of absorption in the interstellar medium.

The situation proves to be analogous when we analyze noise in the interstellar communications line. In the spectral region where the medium is transparent to electromagnetic radiation, the optimal range is determined from the condition of minimum interference. Here, according to the rules of the game we must take account only of the fundamentally ineradicable interference; these rules compel us, in particular, to cancel out of consideration both equipment noise (since this noise in principle can be made as small as we wish) as well as atmospheric noise. The only theoretically ineradicable source of noise restricting the capabilities of interstellar communications is noise caused by natural cosmic radio emission -- the very noise whose study constitutes the object of radioastronomy. Quantum fluctuations in the actual signal under study and noise (so-called quantum noise) represent another fundamentally ineradicable restriction affecting the selection of the optimal range.

The optimal wavelength range for interstellar communications calculated with allowance for emission of background and quantum fluctuations coincides with the short-wave section of the radio range (decimeter, centimeter, and millimeter radio waves), that is, it lies within the transparency region of the earth's atmosphere. However we must bear in mind the following important circumstance. As shown by pulsar observations, the effect of flickering of radio waves associated with their scattering at inhomogeneities in the interstellar medium and earlier well studied in meter waves proves to be very substantial also in the decimeter and, possibly, in the centimeter wavelength ranges. Allowing for this factor, still not adequately studied, must shift the optimal range into the shorter spectral region. It is possible that the region of millimeter or even submillimeter waves will prove to be optimal. In this case transporting communications facilities intended for interchange with other civilizations beyond the earth's atmosphere becomes a necessity for us.

In constructing a system of communications with extraterrestrial civilizations, it is most important to study the effect of the interstellar medium on the passage of radio signals. Owing to the enormous extent of cosmic communications lines, even the extremely rarified interstellar medium has an appreciable effect on the signal. Besides absorption and scattering of radio waves, dispersion plays a key role. In the propagation of a signal in the interstellar medium, owing to dispersion (differences in phase and group velocities of waves at different frequencies), the signal shape undergoes distortion -- the effect of phase shift and the group delay effect. This imposes certain restrictions on the character of the signals themselves; in particular, a lower limit is set to the width of pulses that can be used for interstellar communications. These restrictions must be taken account of both when transmitting signals as well as in constructing the detection system. We must note that the question of the effect that the interstellar medium has on the passage of radio signals, especially distorted signals in the interstellar medium, has been explored very weakly, even though the parameters of the medium are known from astronomical observations. /299

One of the most complicated problems that players in interstellar communications encounter is the problem of the features of the artificial source. In fact, in order to detect a receiving party, one must be able to isolate the artificial source of radio emission, and be able to discriminate it from the enormous array of natural sources associated with the emission of nebulae, galaxies, quasars, remains of flares of supernovae stars, and other natural processes in the universe.

Several radioastronomical criteria of an artificial source have been proposed: small angular dimensions, characteristic spectral distribution of intensity, variability of the flux of radio emission in time, and the presence of circular polarization. The suggestion has also been advanced that an artificial source must radiate in a narrow spectral band to ensure long range and high reliability of communications. The presence of these narrow monochromatic lines can also serve as an indication of the artificial nature of the radiation source.

It is not difficult to trace the principle by which the radioastronomical criteria of artificiality are constructed: they include features that an artificial source must exhibit (based on theoretical considerations) and that natural sources of radio emission do not possess. Of course, this approach is not altogether rigorous. On the one hand, it sets only the necessary, but not sufficient criteria. In fact, even natural sources of radio emission can exhibit properties like small angular dimensions, variability in time, circular polarization, etc., along with artificial sources. On the other hand, if known sources of radio emission do not exhibit specific properties, there is always the possibility of detecting a new class of natural sources with different radiation mechanisms and exhibiting these properties. Therefore along with radioastronomical criteria of artificiality that unquestionably play an important auxiliary role, unique, mathematically rigorous (necessary and sufficient) criteria must be elaborated.

A possible way of formulating such criteria lies in studying the statistical properties of a signal. We can, for example, suggest that one of these features distinguishing an organized "intelligent" signal from an unorganized signal is the presence of a certain redundancy which is required in order to ensure the reliable transmission of information in a channel containing noise. /300
Attention has been directed several times to the necessity of developing statistical criteria of an artificial signal, however, this question thus far has been dealt with only to a limited extent. We must note that the analysis of the statistical properties of a signal in the conditions of observing very weak cosmic sources of radio emission represents an extremely complicated task; this requires setting up special equipment distinct from the equipment ordinarily used in radioastronomy. For example, it is desirable to make recordings on magnetic tape of a high-frequency field

preserving information about signal amplitude and phase, followed by computer processing. Another way of developing rigorous criteria is based on using the theory of complex systems. It is not precluded that the only sufficiently rigorous criterion of an artificial signal is the presence of definite substantive information. We have thus arrived at the problem of deciphering signals.

The problem of deciphering is intimately associated with the problem of language. Both the language of symbols as well as the language of concepts can be used for cosmic messages. The language of symbols is simplest and for creatures like man very graphic. It is not difficult to transmit two-dimensional or three-dimensional image scanning over radio communications channels. The image is easily restored at the receiving end of the communications line, this requiring only that one know the scanning parameters. Evidently, holography is very promising for image transmission. However, we may suppose that images are used only as an auxiliary means. The language of concepts is better suited to transmit scientific information, since the most abstract categories can be communicated via concept.

An example of such a language specifically intended for communication with extra-terrestrial civilizations is the so-called Lincos of the Dutch scientist, Freudenthal. This is a very interesting attempt, but, of course, Lincos cannot be viewed as an ideal language for interstellar communications. In the opinion of Freudenthal himself, this moderately formalized language is intended for communication with creatures that are mentally similar to people. Expressions of the necessity for improving Lincos and of the necessity of devising a more completely formalized language have often been expressed. In the view of Soviet mathematician, A. V. Gladkiy, some other approach must be followed. In his view, it is not the development and improvement of a special formalized language of the Lincos type, but the development of a general theory of language -- a theory that takes shape and develops independently of the problem of interstellar civilizations -- that measures up to the task of "linguistic preparation" for communications with extra-terrestrial civilizations in the best way.

As for the content of interstellar communications, it is usually suggested that they must contain a presentation of the system of knowledge of the sender. Therefore interpretation conveniently begins with the most elementary subdivisions of the system (just as, for example, Lincos is constructed). However, here one very serious difficulty comes to light. In fact, systems of knowledge possessed by different civilizations need not necessarily be the same, and even their elementary components can differ widely. Accordingly, we are faced with the problem /302

The nebula Orion. Several of these nebulae have puzzling strong sources of radio emission.

of the possibility of a meaningful, semantic contact among civilizations. This problem is quite complicated. To some extent it is linked to the problem of whether different forms of life and intelligence exist in the universe. It would be a matter of restriction to assume that all intelligent creatures are physically or mentally like people. We must be prepared for the possibility that the intelligence we may possibly have to encounter and come into contact can take the most unexpected forms. But whereas the forms of life and intelligence in the universe may differ, the conceptual apparatus of different civilizations can be even more different. Can there be two systems of knowledge reflecting the objective world so markedly differing in their concepts that essentially no interaction between them is possible? The initial response of scientists to this problem usually proves to be negative, while mathematicians and philosophers are inclined to answer it in the affirmative. Answering the question hinges on the problem of forming concepts, more exactly, on the problem of reflecting the objective reality by the subject of cognition.

By admitting that there are differences in the conceptual apparatus of civilizations, one would think that among them there may also be found civilizations that have a mode of reasoning and a closely related system of concepts similar to ours. However, this assumption is not very well-founded, for as soon as we admit the possibility that civilizations with entirely different modes of reasoning and with altogether different "nonintersecting" systems of knowledge exist, it is improbable that any of them will by chance considerations have formulated concepts coinciding with or akin to those mankind has elaborated. It appears more probable that specific, "most essential" features of the material world in one way or another are reflected in the process of cognition by any civilization and will serve as a basis for formulating concepts admitting of mutual interpretation without direct interchange between subjects of cognition.

Finally, it can be supposed by virtue of universal communications and the causality of phenomena in the material world, a kind of "convergence" of concepts takes place at sufficiently high levels of abstraction. This also affords grounds for hoping for the possibility of semantic contact among civilizations even if initial starting concepts differ. It is not precluded that an answer to this question will come from an entirely unexpected source: perhaps the study of dolphins will shed some light. Whatever the case, the problem of semantic contact among civilizations is a very profound and complicated problem, bound up with fundamental questions of philosophy in general, and the theory of cognition in particular. /307

Astro-Engineering and Cybernetics

A fundamentally different approach to the problem of the search for extra-terrestrial civilizations free of the above-noted difficulties has been developed by the American physicist, F. Dyson. He draws a clear distinction between intelligence and technology and suggests that we do not seek for signals from extra-terrestrial civilizations, but traces of their astro-engineering activity. Dyson describes several specific projects that a highly developed civilization could carry out. The extremely important conclusion he reaches consists of the following. Independently of specific engineering details, the second law of thermodynamics requires that a technically advanced society consuming a certain amount of energy, let us say all the energy of its star, would irradiate part of this energy into ambient space in the form of spent heat at a temperature lower than the temperature of the working parts of the equipment. Most of this radiation, as calculations have shown, would be concentrated in the infrared spectral region, in the wavelength range from 3 to 10 microns. This radiation cannot be "concealed" regardless of whether the technically advanced civilization wishes or does not wish to conceal its existence from anyone. Dyson's point of view is fascinating in that he does not postulate the goodwill of highly developed civilizations (do they even wish to transmit /304 signals to us?), but simply suggests that manifestations of their astro-engineering activity be observed. The weak link in his concept is the fact that it is based on the orthoevolutionary hypothesis (the unbounded quantitative growth of civilizations).

In this sense, the cybernetic approach to the problem of detecting extra-terrestrial civilizations developed by Soviet radio astronomer, B. N. Panovkin appears logically more irreproachable.

Considering an extra-terrestrial civilization as a complex cybernetic system, and the radiation associated with its life activity as an output response of this system, on the basis of an analysis of radiation one can draw certain conclusions as to the functional structure of the system and its internal organization (just as we do with respect to all other celestial objects), regardless of whether a system tries to communicate this information. For example, based on the properties of radiation it can be established that a system belongs to a wide class of objects in which feedback is present. From this class, after a more detailed analysis, a narrower subclass of systems can be discriminated in which homeostasis is manifested. From the class of homeostatic objects one can isolate a group of objects possessing even more complicated functional properties (for example, "systems logic"), etc. Ultimately, in principle it is possible to isolate a class of objects which (regardless of their material structure) can be recognized as equivalent, let us say, to our earth civilization in terms of their functional properties and their manifestations.

An attractive aspect of this method is the possibility of consistent and well-defined formulation of the research problem, and the exclusion of indeterminacy in the interpretation of phenomena from the standpoint of "artificiality". In practice, the problem of course is extremely complicated and its solution doubtless will stretch out for many years. But it is not in this that its main difficulty lies: we do not know whether it is possible in general to actually realize the program formulated.

Solving the problem can be greatly simplified if the system (cosmic civilization) sends special signals whose structure embodies information concerning its internal organization. Detection of such signals can be done on the basis of methods developed by the theory of interstellar communications. In this formulation, the systems approach essentially merges with the communications aspect of the problem of extra-terrestrial civilizations; here we again encounter the problem of call letters and the problem of relative signs of an artificial source, since they facilitate the detection task. However, the difficulties associated with the exchange of semantic information, and the problem of language and "mutual comprehension", which was discussed above, disappear altogether.

The cybernetic, systems approach to the problem of the search for extra-terrestrial civilizations is marked by the greatest methodological rigor, however in the practical sense it still is very ineffective. In the history of science and technology there have been numerous examples when results of practical importance were achieved at the cost of rejecting excessive rigor /305
and at the cost of a reasonable simplification of a problem. Essentially, the difference between the fundamental and applied sciences (including the applied divisions of mathematics) lies in the different approach to the criterion of rigor. Often methods that are productive in a practical sense only later are given a rigorous logical foundation (for example, the foundation of differential and integral calculus was given only in the 19th century). On the other hand, the substantiation of methods employed, a rigorous formulation of a problem, and analysis of starting concepts not only aids in outlining the scope of their application, but also opens up completely new vistas.

It therefore appears unquestionable that in a little-explored field such as the problem of the search for extra-terrestrial civilizations, a combination of methodological rigor in formulating the fundamental problems of investigation with the solution of practical problems of interstellar communications and with the development of specific detection systems is particularly necessary. Only this combination, only the broad treatment of the most diverse ideas and methods can ultimately lead to success.

CLARITY IN FORMULATING THE PROBLEM IS VITAL

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B. N. Panovkhin, Candidate of Physico-Mathematical Sciences

From the "naive" point of view, the problem of extra-terrestrial civilizations appears to be quite transparent. We must search for civilizations, and detect them, communicate with them via radio signals, etc. In this narrowly astronomical aspect, the difficulties appear to be purely technical: long distances, interference of the interstellar medium -- and hence the complexities in discriminating "useful signals."

A more attentive study reveals that success in solving the problem is associated, first of all, with the clarity in our concepts of many very "earthly" matters. Statements from the standpoint of "obviousness" and "common sense" often prove to be the most dangerous for fruitful progress. The theoretical value of the problem (and we do not have experimental data) evidently consists precisely in the discussion of "obvious" concepts in order to find in them the universal, which can be extrapolated to other hypothetical highly organized systems in the universe.

Refinement of the meaning of such fundamental concepts as "life" and "intelligence" would lead to clarity in formulating the problem of their detection.

WHY IS THE WORLD IN WHICH WE LIVE THE WAY IT IS?

Ya. B. Zel'dovich, Academician

I will not attempt to predict precisely what science will discover in the immediate future, but I would wish that this is the initiation of an approach to cosmology that would enable us to discover why the world in which we live is precisely the way it is, and not something different, to discover what brought about the initial conditions of evolution. Thus far physics have dealt with laws in which an initial condition must postulated -- roughly speaking, the initial velocities of some moving bodies and their initial position. But the very question as to the initial conditions thus far lies beyond physics. And if we do not accept the postulate that the primordial motion was caused by some divine force, then we must find a scientific approach to the problem of the choice of initial conditions.

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LINCOS -- AN INTERPLANETARY LANGUAGE

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H. Freudenthal, professor (The Netherlands)

The limits to mathematics are widening. At the close of the last century, mathematicians began to be interested in linguistic problems. True, mathematics has nothing in common with ordinary languages, they are too awkward, too irregular, too irrational, and too illogical. But there is one language in which mathematical methods can be used: the language which mathematicians themselves use. By this language I mean not only the entire wealth of mathematical formulas, the combinations of numbers and letters representing numbers with algebraic symbols, words like log or sin and strange symbols, but also all the words and symbols taken from the ordinary language that can be found in handbooks among formulas: terms like "it is given," it is required to find," "therefore," "we note," etc.

Mathematical formula language has a long history. At the close of the last century Italian mathematician, Peano, took a step to a more radical formalization of mathematical language. He attempted to embody in formulas not only the object of mathematical thought, but mathematical thought itself: the expositional expressions with which mathematical formulas in textbooks and reference works are surrounded. He invented methods of translating into mathematical language such logical combining expressions as "and", "or", "not", "it follows", "there is", "each", taken from ordinary language. Besides a new lexicon, a new grammar was necessary -- a new syntax, as logicians put it. Since them this language of formulas has been well developed by the joint efforts of many mathematicians. Among the mathematicians participating in this development, Russell and Whitehead are the best known, who early in our century converted much of mathematics into the logistic language.

It is strange that this language is very little used as a means of communication between mathematicians. On publishing new discoveries, scientists adhere to old habits and continue to use ordinary language. Perhaps, the logistic language appears to them too awkward. Perhaps, they are repelled by the thought of studying a new language. Meanwhile, the logistic language has proved to be a very valuable adjunct in the field of mathematical philosophy and communications.

We all know very well that ordinary languages give little ground to logic. Anyone can agree with no difficulty that the vocabulary of ordinary languages is logically weak, that the

meanings of particular words may differ. But not everyone recognizes that the syntax of ordinary languages is even more arbitrary and random. Everyone who studies higher mathematics encounters this problem in his very first lectures: ordinary languages are not devised in order to express mathematical thought and it is /307
difficult to adapt them to the precision of mathematics.

In this respect, all languages of western civilizations are similar to each other. They have the same fundamental syntactic structure with main and dependent clauses, with subject and predicate, with connective particles and interrogatory phrases. This system cannot have developed in different languages independently of each other. At some time in history syntax was more logical and approximately more closely the syntax of modern logistic language. Then, at the close of the second millenium before our era, some sort of language revolution occurred. Relative clauses and similar devices were invented.

In ordinary languages there is a vast number of ways expressing subordination: conjugation, relative pronouns, word order, verb tense, subjunctive mood, replacement of some variables by others (for example, "he" instead of "thou" in the phrase: "I said to John that he must come"), etc. Logistic language, just as mathematics, utilizes instead of this various kinds of brackets in order to show what parts of the text are associated with each other more closely than with other parts. The brackets serve a function somewhat like punctuation marks.

Evidently, syntactical subordination is expressed by punctuation signs, which at one time were oral, resembling pauses and changes in intonation. Our present-day system of subordination probably arose with the appearance of writing. In modern languages punctuation is scarcely more than simple convention. But in the logistic language the entire syntactic structure of a phrase is determined by punctuation. Using various types of brackets, as in mathematics, long chains of subordination can be formed. A chain consisting of 20 components, each of which is subordinated to the preceding, is by no means a rarity. In ordinary languages such structures would be incomprehensible. Of course, the logistic language also is concerned with clarity. A handful of round, square, and curved brackets would only complicate a text. There are even more effective methods for punctuation, but they probably are beyond the limits of this article.

Another distinction between the logistic language and the ordinary language is the question of so-called variables. A variable is something like an empty cell that takes on a certain meaning only after it has been filled. An example of this variable can be the word "dog" as a designation of any individual dog. But it becomes the name of some particular dog if I say "the dog of

Mr. Johnson" or "the dog sitting at the street corner." The word "I" is a variable that becomes the name of the one who pronounces it. The word "now" is a variable which, on being spoken, denotes the moment at which this word has been uttered. In ordinary language there are different kinds of variables, each of which serves a specific purpose: "now" always refers to time, but "she" is used always for objects and events related to the feminine gender.

But in the logistic language variables are completely empty cells. Each of them can serve any purpose, and this purpose can only be indicated by the context. The variables are limited by /308
the explanations of the brackets. Usually the process of restricting a variable is called combination. If a variable x must apply only to a class of persons, the definition "x" is a person is added in brackets. Then the variable x "must" apply to people. A sentence like "A woman living across the street has a servant who used to work for my mother" is given approximately the following form: "x_(x stands for a woman living across the street) has a servant y /y previously worked for z (z is my mother)_7." These constructions are possible owing to the methods of punctuation adopted by logicians.

In addition to the kinds of combination serving to define variables, there are also other ways. In the sentences "An automobile is in my possession" and "An automobile is a means of transportation," the variable automobile is defined by different methods, though the word "is" is used in both cases in ordinary language. The first sentence applies to a single automobile (though if I have several, then I must specify which one). The second sentence says something about all automobiles. In the logistic language the first sentence takes on this form: "There is a certain x (x is an automobile and I possess this x)," and the second takes on this form: "For each x /(x is an automobile) it is valid that (x is a means of transportation)7." But the same forms are used in ordinary language in both cases.

Mathematicians have to use words with care. This is one of the main rules that anyone specializing in higher mathematics must master. He must be continually on the watch for any vagueness, especially if different connections are used in the same sentence.

Logistics is essentially nearly syntax. If we wish to use it in practice, we need a dictionary: names for persons and for their actions, if we wish to describe ordinary situations, or names for physical concepts if we wish to say something about physics. The problem of the dictionary by no means is among the easy ones. And not because the material is lacking: rather, because the choice of possible solutions is extremely rich and it proves difficult to decide what to take and what to reject. This characteristic is well known in every field of learning. The first step must be to formulate one strictly specific, even limited problem. In this case I choose the problem of constructing a language for contact with intelligent creatures that do not know any of the languages on our planet and to whom we cannot show objects. We must assume that these creatures are similar to people in their mental abilities and development, though of course, this does not necessarily imply external similarity.

This problem was the basis of the humorously written, but quite serious article published in 1896 by the brilliant mathematician and anthropologist, Francis Galton. Nowadays technological capabilities for cosmic contact have taken form much more favorably than in Galton's time. We now have electromagnetic waves with which we can send radio signals into space. I do not know what their operating range is today. I am not a specialist in communications and I offer these problems quite willingly to more competent persons. /309 I also cannot say whether there are actually intelligent creatures anywhere in the universe who could pick up and understand our signals (though in this respect my lack of knowledge is no more greater than anyone else's). However, it is difficult for me to believe that our earth is the only point in the universe inhabited by intelligent creatures, though I am ready to admit that our nearest neighbor can live thousands or even millions of light years from us.

But then it may very well prove to be that the idea of a cosmic language has been overdue. It may be that news from far-off worlds has been steadily rushing here and there in outer space on the ether waves and from us it is only required that we listen to them. It may be that they are carried on long waves not capable of penetrating our atmosphere and in this case we have to listen to them from some cosmic advance post, from another satellite, and there construct a station in order to switch into the universal network of communications. But this is a fantasy which astronomers and physicists can deal with. But let us turn to the actual subject of this article.

I have made several drafts of a language for cosmic contacts, which I call Lincos (an abbreviation from the complete name "linguictics of the cosmos"). Doubtless the reader will find that thus far I have done very little. A vocabulary consisting, let us say, of 200 words, not including purely mathematical and logistic terms, would require a volume of several hundred pages. But this is only the beginning. My dictionary is only approximate. It must receive close criticism and analysis in order to avoid lack of coordination and overly cumbersome constructions. Even leaving to one side the technical difficulties, it can scarcely be anticipated that in the future we will be able to speak with other worlds using Lincos.

Radio signals of different duration and in different wavelengths serve as the sounds in Lincos. Words are formed from these sounds. In only several cases do I point out how to put together a word: for most words this is not a central problem, and it can be solved in the future. Instead of words specifically consisting of radio signals, in my text I use arbitrary coded words. These words are in most cases abbreviations of Latin words understood from their English and French cognates.

Sentences can be constructed of these words, and from sentences -- programmed texts. Let us assume that listeners pick up a flow of signals as a language, and not as music of the spheres. If the listeners are similar to man, then they will deal with these messages just as we ourselves would deal with them: they will try to decipher them. The language is unknown to them, but in one respect it will be easier for them than for cryptanalysts of diplomatic or military codes. These codes are constructed in order to withstand all efforts at deciphering without the key, while in messages sent in Lincos we do everything possible to make the text comprehensible for the listener.

Since the time of Galton, more than communications technology has advanced. The construction of the space language became possible owing to the labors or modern logicians. The skeleton of the structure -- the syntax -- is already at hand. Now it remains only to fill it with concrete and to lay the bricks, that is, to set up the dictionary. Let us remind the reader of the extreme simplicity of logistic syntax: it has no conjunctions, no nouns, no verbs, no declensions, no conjugations, no tenses. This is simply a system of punctuation. Pauses will play the role of punctuation in Lincos transmissions. The longer the pause, the more the punctuation mark will be emphasized. The listener will understand this principle without explanation if he picks up anything at all. The pauses will speak for themselves, and the listener will notice above all that each phrase is marked off with pauses: a syntactic analysis at first glance. /310

But what then will we transmit? How will we begin? With mathematics, of course. We cannot attempt to represent anything visually, since we cannot begin with anything concrete. And there is nothing more abstract than mathematics.

First texts will be something like this: four dots, a complex we will call pof, then two dots, another complex we designate with rik, and then six dots. Next: seven dots pof nine dots rik sixteen dots. Or: three dots pof eleven dots rik fourteen dots. The reader -- and the listener anywhere in the universe -- can understand that pof means "plus" and rik means "equals". But this is a little ahead of ourselves. We can also understand from the text that pof means "equals" and rik means "less than".

So this is a plainly unsuitable beginning. Constructing a language is just like walking through a field scattered with traps and I am sure that I have fallen into more than one. But let us begin a little more cautiously, with sentences containing not more than one doubtful word, for example: four dots rik four dots, etc. When the meaning of the word rik becomes clear, we can send sentences of this type without any risk. In exactly the same way we can introduce words denoting other main arithmetic operations, and terms denoting "more than" and "less than." We will simply send numerical formulas in which these words are present. Not counting the infinite series of numbers 1, 2, 3...,represented by one, two, three, etc., number of dots, and then we will have at our hands a vocabulary of seven words.

The dot dash numbers of course will later on prove inconvenient. At the appropriate time we will transmit a list showing the listeners how to read numbers in a more compressed way. Of course, we will use not the decimal system, but the binary system, since we have no reason to assume that intelligent creatures on other planets have ten fingers on their hands and feet. But for the convenience of readers on earth, here I will stick to the decimal system.

The next step will be to introduce variables. We draw up series of equations, for example: 3 + 7 = 7 + 3; 3 + 11 = 11 + 3; 3 + 1 = 1 + 3; 3 + 8 = 8 + 3 and finally, 3 + a = a + 3, from whence the listener can understand that the unknown complex a must signify a variable. Gradually these formulas containing letters will become more and more complicated.

Then we can introduce the first logic symbol. We transmit pairs of algebraic formulas: in each such pair the second element will always be derived from the first, and between them will stand a word that must be understood as "follows". From the context the listener will understand that this word actually has this meaning. At the same time we can introduce words like "and" or "or". /311

Zero, negative numbers, and fractions can be derived from texts similar to texts in a school algebra book. The next step will be to introduce decimal (more correctly, binary) fractions. Simple fractions are converted into the binary system. And after periodic fractions have been introduced the listener can become acquainted with the term that serves as a key to all of mathematics: the term "etc.", one of the most common in Lincos. Then words denoting "integer" and "fraction" are introduced, along with the word "is" used in a sentence like "3 is an integer" (in fact Peano found that the word "is" differs from the synonym for the word "equals" used in the sentence "3 + 4 equals 7").

The most difficult problem is how to introduce the words "there is" and "for each", but when this obstacle will be overcome, mathematics can develop along classical formulas.

The second chapter in the Lincos project deals with the concept of time. Here a complex consisting of a still-unknown word, for example, dur, is transmitted, a fairly long dash, along with the word denoting "equals", one more unknown word, for example, sec, and finally, a number expressing the actual duration of the dash in seconds. Thus, the complex of signals will denote that the duration of the dash is equal to some number of seconds. This same complex will be transmitted also with another duration for the dash (and therefore, with another number following it). If this is done several times, the listener will observe that the number in the signal is always proportional to the length of the dash and will conclude that the word dur denotes duration, while the word sec is the unit for time we use (here we must vary the length of the wave for the dash, or else the listener would not assume that the word dur relates to the number of waves contained in the dash).

Now the listener has become acquainted with our unit of time (although to some extent it will be distorted to the relative movement of the transmitter and the receiver: if they are approaching each other, the dash will become shortened, and if they are moving apart -- the dash will become longer).

The words "wavelength" and "frequency" can be introduced at the same time as the word "duration". In exactly the same way we can introduce the concept "before" and "after" -- using two dashes in different wavelengths and a text that states: the dash in wavelength x before (or after) the dash in wavelength y. Then we can transmit on a specific wavelength the ticking of a clock lasting throughout the entire program and add instruction on how to "read" the clock. Next, if we wish to speak about a past or future event, we can communicate its date. On recalling events, we can illustrate them with many examples: some event occurs (for example, a complex sequence of signals), and then it is stated that "between the instants t_1 and t_2 such and such and such and such took place," where the words "such and such" and "such and such" are replaced with a copy of the preceding event. Thus, the listener will learn yet another word denoting "occurs".

The third chapter of Lincos deals with "human behavior"; this chapter is the most important and now the most difficult. Actually, we can tell the listeners about people only in the language of abstraction. Just as we represent numbers by a sequence of dots and duration by a sequence of dashes, now we proceed similarly in representing human behavior in the form of some radio play. The actors will be arbitrary names like A, B, C, etc. Of course, /312 these actors must show some activity, and since we have no words to signify space or motion, the only allowable form of their activity will be speech. Speech means communication; at the present time it is not important which physical methods of communication are adopted on earth. But besides actors and activity we also need some method in order to distinguish the good from the bad, since action cannot be based only on the good. Therefore, we must also introduce the two words "correct" and "incorrect", and the actors will say them as a sign of approval or disapproval.

Finally, we must decide what the actors are to talk about. Of course, about mathematics since we have outlined mathematics in detail and we do not have any other subject. The conversation will be made up of questions and answers, as in a class.

The first talk can go as follows. A says to B: "?" (x = 2 + + 2)". B answers A: "4". A says to B: "Correct" (the connection "?x..." is known from chapter one; it denotes "find x such that ...").

A sufficient number of such conversations will be transmitted. The sequence of alternating questions and answers will give the impression of a conversation and the listener will guess what the word "says" means and that A, B, C, and so on are the names of creatures capable of talking to each other. Since correct answers are accompanied by the word "good" and the incorrect answers -- by the word "bad", the listener will understand what these words mean. Let us note that "good" and "bad" are not the same as "correct" and "incorrect". If to the question "How much will 2 + 2 be?" the answer "2 + 2 = 2 + 2" will be given, this answer will be "correct", but not "good".

In these talks we can do without interrogatory forms since each question can be formulated as a problem to find an unknown. Thus, instead of "Who says A 2 + 2 = 4?" we can say "?x (x says A 2 + 2 = 4)". Or instead of "What does A say to B?" we can say: "?x (A says x to B)". And finally, "Does A say to B: 2 + 2 = 4?" can be expressed as: "?x [x = the truth (A says to B: 2 + 2 = 4)]".

Now we can move on to representing several other actions, which essentially are nothing other than variants of the speech act, in most cases a conversation with oneself. A series of dots is transmitted and at the same time A counts them, that is, pronounces the names of the numbers. Then B states: "A is counting". Or else we listen to A doing the counting and then B says: "A has counted". Or else A tries to find something (for example, the first prime beyond some limit -- by calculation or else a person saying something -- by repeating the question "Did you say that...?", and then B says that "A has searched (and found)". In a similar way we can explain the concepts "proved", "described", "changed", "added", "omitted", and so on.

The concept "to know" is much harder. A conversation is /313
going on in which A asks of B: "How much is 2 + 2?" B answers: "4", and then A states that B knows. But this is insufficient. The meaning of the word "knows" is better shown with less direct indications. For example: A asks of B: "How much will 2 + 2 be?" and B answers: "4"; then A says: "B knows what I have asked about". Or a melody is transmitted and when B sings it, B says: "B knows what has been transmitted".

The next word is "to guess". It shows up when B knows about some event although no one told him about it; B learned about it as soon as it happened. Therefore A says: "B guessed about it". This word requires a broad context. The words "to understand" and "to mention" are easier. They can be illustrated with simple examples.

The word "nearly" or "approximately" are very important and quite easy. Approximate solutions of algebraic equations, the approximate reproduction of sounds and so on will aid us in inserting this word into context. By comparing various approximations we arrive at the concept of the error of an approximation. When use of the word "nearly" becomes understandable, words like "much" and "little" pose no difficulties. Now we can replace the precise chronology obtained by counting by the hours with an approximate chronology. This means that we can introduce the concepts "recently", "soon", "long ago", and so on. "Now" also belongs to this group of words. It is defined with the aid of a sentence like the following: "Every time it is encountered, the word now denotes approximately the moment when it is pronounced."

The words "necessary" and "possible" ("to be in a state") are extremely difficult and require a rich context. The "age" (of a person) is a relatively simple word. A says that B cannot know about some event since it occurred too long ago and hence C concludes that the age of B is less than some number of seconds. The beginning and end of the "existence" of a person are defined as the limits in which an individual can observe something -- this preliminary definition is sufficient for the time being. We can add the pattern of an individual's development: at which age does a person begin to talk, count, make calculations, solve quadratic equations, and so on.

Here a new actor appears -- D. He can observe events and utter incomprehensible sounds but he cannot speak, count, make calculations, and so on. Then it can be explained that A, B, and C belong to the class "man", and D belongs to the class "animal"; for the moment we will not differentiate this class. But here we can give a statistical review of living mankind by ages.

Now we can turn to a category of words like "to wish", "to enable", "to be forced", "to be allowed", "to be forbidden", "properly", and "politely". A person being addressed refuses to answer: "I do not wish ...." The person states that he or others intend to do something, using the formula "I wish...." The two promise each other to do something, and a third person concludes that they are therefore *obliged* to do this. A liar is *forced* to tell the truth. A student is *forbidden* to whisper. It is allowed to say: "I want you to do this," but the more *polite* formula- /314
tion will be to say: "I wish that you would do this".

This conflict between necessity, duty, desire, force, and possibility reaches a peak at the close of the chapter on human behavior when games are arranged with the actors. These games will be terminated by the "victory" of one of the partners and the "defeat" of the others. Suppose A and B play a very simple arithmetic game: they alternately read off the numbers from 1 to 10, and these numbers are summed up. The one who first gets to 100 wins. Or let A and B play something like "coin-tossing": at the same time and independently of each other they say: "one" or "two". If they pick the same number, A wins, and if different numbers B wins. Then, finally, there are games for three: two can unite against the third, who will attempt to break up this union by promising some advantages to one of the members.

Though the subject matter of the talks is still confined to mathematics, the behavior of the actors is predominantly rational, but already an emotional background to this behavior can be noted in this behavior. We now can show the fairly complicated nature of the relationships by the following example. A makes a declaration of some kind to B. Then he observes that what has been said may have been heard by C. He asks C whether he heard it, and C answers in the affirmative. Then A asks whether C would be so kind as to forget it. C answers: "I will try to forget, but I do not know whether I can for much is forgotten right away, but there are things a person remembers his whole life. It is easier to forget what you do not wish to forget, than to forget what you wish to forget."

Twice as many words are needed to transmit this scene in Lincos as in English, but the average length of a word in Lincos is only one-fourth the length of an English word. Punctuation to the 12th degree is used in this text.

Chapter four in the Lincos draft deals with mechanics, but human behavior continues to play a role in it, though at another level. The human creatures we have become acquainted with in chapter three can have only one measurement: time. Nothing has been said either about the space in which they move or about their bodies. The actors speaking and expressing their desires, playing and battling with each other are still only hazy shadows. /315

The first new concept introduced in this chapter will be the concept of a difference in position. Suppose A and B observe the same event at different times. Therefore, they are in different places. Thus distance is defined: between A and B it is proportional to the delay in the signal from A to B. Then space is defined as something encompasses all positions; distances are given in it. After this experimental introduction, we can define space and distance purely mathematically, using analytic geometry. Thus, figures in space can be described by using formulas. True, listeners still will not be able to know our measures of length. The only absolute measures we can introduce at this stage are average growth and average volume of an adult person, and from these data we can derive only the most approximate values of our measures.

The concept of motion is introduced so that we can speak about people and animals changing place and then this is given a precise mathematical definition. People and animals are able to move as they will, objects cannot. People and animals can bring objects toward themselves or separate themselves from them, they can pick up and throw them.

Waves and oscillations are a special kind of motion. There are oscillations propagated at an enormous velocity; they are called light. We can also communicate about the speed of light and listeners, more or less familiar with our unit of time, will convert our measures of length into theirs by comparing our data with theirs. Then we can transmit a formula in which the wave- /316 length emitted by the hydrogen atom appears. The so-called Rudberg constant, from which our unit of length can be very precisely derived, appears in this formula.

The next concept is the concept of mass. An actor says that of two objects, one is much heavier to carry than another. Their volumes are the same so that the difference is due to another factor -- mass. Then we communicate about collision and explain the classical laws of elastic collision. From this the listeners can find out what precisely we mean by mass, though our unit of mass is still not known to them. Then we can describe the phenomena of gravity and give Newton's law. Comparing it with the laws of "their Newton," the listeners can calculate our unit of mass.

These have been the main concepts of mathematics. Moreover, we have shown that people, animals, and objects have one characteristic that we can call a body and that can change in the course of time. We can indicate the mean mass of the human body and communicate that the existence of this body begins somewhat earlier and lasts somewhat longer than the existence of the individual to whom it belongs. Then we can describe how and where the human body originates.

Following this, we can communicate about bodies with masses so great that they must be celestial bodies: about the sun, the planets, and the nearest stars. We can present the masses, orbits, velocities, and other characteristics of the planets in our solar system and indicate that people live on one of them. If we now transmit a map of our part of the universe, the listener in another stellar system can look for the point at which mankind lives.

The fourth chapter can be concluded with a brief presentation of the theory of relativity -- this is essential since without it serious gaps will appear in our transmissions. In later chapters it is planned to examine matter, geography, anatomy, physiology and once again -- human behavior. These chapters are yet to be developed. Thus far, the four subject areas outlined here furnish enough material for the first book on Lincos.

MATHEMATICS IS AN INSTRUMENT FOR UNDERSTANDING THE WORLD /314

B. N. Panovkin, Candidate of Physico-Mathematical Sciences

We cannot agree with Freudenthal's statement that mathematics is supposedly a subject most abstracted of the specifics of human cognition of nature and therefore that mathematical properties are most "objectively" and "absolutely" intrinsic to some essence of phenomena in the external world.

Our mathematical concepts are also the products of the highly abstracted activity of the human mind.

Mathematical structures are not "present" in the objective world -- mathematics is a powerful instrument of human cognition corresponding to a description of reality.

Several mathematical concepts reflect several aspects of objective reality, but reflect them in a form interpreted by consciousness -- as idealized logical schemes that incorporate, as a fundamental component, also the idealization of the corresponding method of cognition.

LINCOS -- AN ARTIFICIAL LANGUAGE OF SCIENCE /315

L. A. Kaluzhin, professor

In the form in which Freudenthal has devised it, Lincos can be hardly utilized for radio transmissions to any planetary systems however remote .... Essentially, this goal is only a convenient pretext for the author to develop some artificial language of science that combines the advantages of the formalized languages of mathematical logic, on the one hand, and the flexibility and wealth of natural living languages -- on the other.

FROM THE RESOLUTION OF THE FIRST INTERNATIONAL CONFERENCE "COMMUNICATIONS WITH EXTRA-TERRESTRIAL CIVILIZATIONS"

"In a number of specific details in this problem area, the views of conference participants fail to agree, but participants do agree that the prospects for contacting extra-terrestrial civilizations are sufficiently favorable so as to justify carrying out several well-prepared search programs; they are also agreed that existing technology makes it possible to establish contacts with extra-terrestrial civilizations."

6. MANKIND -- A COSMIC CIVILIZATION? /317

"In the geological history of the biosphere an enormous future unfolds before mankind if he will seize it and will not use his intelligence and his labor for self-destruction."
V. I. Vernadskiy

The potentialities of mankind are tremendous, witness the irresistible surge of science and technology typical of the modern scientific-technical revolution. Flights have already been made into space; we are gradually conquering near-earth space; we are probing the planets nearest the earth with spacecraft. Developments are underway in actual manned flights to other planets in our solar system. Problems of possible interstellar flights are being discussed. On the agenda is the discussion also of the philosophical problem of the cosmic role of mankind.

Until recently discussions on all these matters were abstract, but now when the investigation of the problem of inhabited space pursues practical aims, study of the question as to what mankind's cosmic role is becomes increasingly urgent.

But we must always remember that only establishing worldwide a truly just society that knows no form of suppression of man by man, a society founded on scientific fundamentals and scientifically managed is the sole way by which mankind will gain the moral right and the actual capability of evolving into a cosmic civilization, if this will be discovered by us.

SPACE AND MAN

/318

E. Kolman, Academician of the
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The surge in society's requirements is due to two factors -- the rise in the population on the earth and the growth in the requirements of the individual. As historical facts show, the population growth rates (in spite of fluctuations caused by wars, epidemics, and so on) have steadily accelerated owing to a rise in the mean birth rates and a reduction in mortality through improvement in living conditions. We will not attempt to guess whether or not these rates will increase in the future, or else if mankind at a certain stage in its development, based on new discoveries it achieves that are fundamentally different from today's technical-economic and social conditions, begins to regulate these indicators. But if we digress from these possible changes and assume that present population growth rates of the earth as a whole persist for the next century, the number of inhabitants on our planet, now estimated to be more than 3 billion, will nearly double by the beginning of the 21st century, and will increase 20 billion in 100 years. As far as the personal requirements of each individual for food, housing, clothing, all material and cultural goods, they will also rise rapidly. And meeting the mounting living requirements of the human society will demand more and more resources -- energy and material.

In pondering on its future, mankind already needs to begin conquering outer space and other planets.

Even if it is assumed that in the future the entire thickness of the crust will be completely utilized, it is obvious that sooner or later the time will inevitably come when to meet the unboundedly growing demands of the swelling population of the earth raw material that the limited mass of the earth's crust can provide will prove to be inadequate and depleted. One will have to think seriously of exploiting the moon and other cosmic bodies.

Cosmic raw material will become even more essential because by that time earth material will prove to be deficient not only as a source of raw material, but even as a source of energy. Although unutilized reserves can from our present point of view be regarded as virtually inexhaustible -- we have in mind first atomic, and then thermonuclear energy, in the remote future we will have to seek again beyond the limits of our planet for reserves of material (possibly the smaller planets -- asteroids -- will be used) that could serve for the generation of energy.

However, the contradiction between the restrictedness of the earth and the relative unrestrictedness of the multiplication of the human species and its requirements is not the only impelling force that compels us to push out into space. /319 Though the mechanical stability of our planetary system, and even the radioactive and thermodynamic stability of the sun are extremely great, they nonetheless are not limitless. At some time either the earth will move away sufficiently from the sun, or else the sun will sufficiently cool off which will negate the possibility of life on the earth for mankind, or else, in contrast, life for people will become impossible here because the earth will draw too close to the sun. Though the probability that any of these alternatives (modern astronomy is not yet in a position to reliably predict precisely which one will occur and when) will take place before a hundred million years is negligibly small, mankind must not passively await its threatening destruction. Science and technology of a future so remote will find ways to preserve the human species.

Whether people will regulate the earth's orbit as they wish, whether optimal conditions essential for life will be maintained artificially on the earth, whether people will migrate to other cosmic bodies, possibly even bodies constructed by man, or perhaps whether they will move to another planetary system (if such will be discovered) -- in any case these or other methods that today our fantasy can scarcely imagine will in one way or the other involve mankind's departure into space. The present first bold steps of astronautics are by no means premature. From here begins the epoch of prolonged preparation for the process of cosmic transformation of mankind, a process which involves in it also changes in the biological nature of man, in his adaptation to conditions distinct from terrestrial.

The third factor impelling man to penetrate into space is the very essence of the process of cognition.

Cognition always strives far beyond the limits of the object directly under study and inevitably seeks for connections with the phenomena most remote in space and time. /320 The very material unity of the world and its dialectic have given a connection between any single object and all of existence as a whole. Therefore in order to understand a single phenomenon, we must understand the entire world (and also vice versa). Investigation of earth phenomena is incomplete without exploring space, without penetrating it, without mastering it.

Earth physics, chemistry, geology, biology, and also psychology and sociology as well will more and more become space sciences with growing penetration into space. The "final" solution (more exactly, the relatively "final") of many of the truly most difficult problems of the structure of matter, the origin of the solar system, the development of the earth, the origination and evolution of organic life, and mental and social regularities will evidently become possible only when we through astronautics expand our knowledge by studying phenomena occurring on other planets, and in the future, in other stellar systems as well.

Discoveries in space will liberate man from many restrictions. As a result, we will reject the notion that earth regularities need necessarily be typical for all of the universe. It is possible that there are not.

However, many of these fundamental problems that do not lend themselves today to solutions have not only theoretical, cognitive, and world view, but also highly practical importance.

In order to show how obvious the practical importance of these problems is, we need cite only one example -- the significance of investigating the question of how our planet began.

Cosmogonic hypotheses now held represent the initial stage in the earth's history in diametrally opposite form. According to the views of some astronomers, geologists, and geophysicists, the earth on emerging from hot gas streaming from the sun was initially an incandescent body which gradually cooled. Other /321
scientists believe that the earth emerged from a dust cloud surrounding the sun, was initially cold, and began to heat up only due to radioactive and tectonic processes. If the former are correct, the earth's crust is slag formed on the surface of an incandescent mass. But if the views of the latter are valid, the crust is an inseparable constituent part of our planet. Correspondingly, the earth's crust must have a different history and structure. But on this must depend the direction in which the conditions of the formation and distribution of deposits in the crust, bedding and composition of metal ores, coal, petroleum, salts, construction materials, groundwater and gases are investigated. In considering which of the hypotheses are true, we therefore have to radically improve the exploration and utilization of natural resources and increase the well-being of people. But this can be done only by solving the cosmogonic problem; and this takes investigating the structure and reproducing the history of the moon, Mars, Venus, and so on, and if possible visiting them.

Penetration into space is already providing and will provide in the near future directly tangible practical results for our everyday life, though we do not always recognize this. First of all, many instruments specifically invented for artificial satellites and space rockets have proven very useful also for earth purposes. Secondly, special artificial satellites like relay stations for radio and television will enable us to make broadcasts for the entire globe. Thirdly, weather satellites make it possible to construct a precise model of the earth atmosphere and to keep track of it for changes and thus ensure reliable long-range weather forecasts. The value of these forecasts for agriculture, for many fields of industry, for transportation, and communications is difficult to overestimate. Fourthly, astronautics spurs advances in many industrial fields that without it would scarcely develop at as rapid rates /322 and without it the amazing successes that have occurred in electronics, radio engineering, remote control, the chemistry of refractory materials, rocket fuels, and so on would have not been achieved.

Changes that the mastery of space will mean to man will be diverse and profound; today they can be foreseen only in most general outline. But one thing is indisputable: penetration into space can become a powerful factor for the unity of mankind.

Actually, carrying out tremendous projects of conquering the moon, investigating Mars and Venus, and later -- visiting regions of even more remote planets, and even still later -- building a rocket that can break away beyond our planetary system -- all this requires such a tremendous concentration of scientific and technical facilities and such enormous outlays of materials and energy which only the united efforts of all mankind could carry out. Thus, from the first scientific-technical competition by the force of internal regularities in the development of science and technology, we must inevitably arrive at an ever-broader and ever-closer constructive collaboration. This process in some respects is similar to what was responsible for the very possibility of the birth and development of astronautics: in spite of growing specialization in all fields of science and technology, the prerequisite for astronautics was and is their joint purposeful work.

In discussing the changes that the mastery of space will bring to social life, here we will limit ourselves only to examining the "immediate future," that is the time measured in centuries and not in millenia or millions of years. (Not because we feel attempt to give predictions this long-term are unjustified: in our view they are quite appropriate and instructive, in stimulating creative reasoning, though inevitably they contain no small amount of fantasy.) We will not here begin to examine the consequences which encountering (or even establishing contacts) with some other, extra-terrestrial civilizations will entail for mankind, if they exist. And not because, of course this possibility is absolutely precluded, but because owing to the extreme diversity and tremendous wealth of the forms of nature, intelligent inhabitants of planets around other stars can prove to be so different from us, from people, that we can by no means preguess what contacts between us and them would result. /323

And thus, let us with many qualifications examine what changes will appear in economics and technology, in politics and law, in science, philosophy, and in art, and in the very physical, mental, and moral shape of man owing to his entry into space.

The economic potential of mankind, in other words the sum of the capabilities determining its technical-economic ability to carry out given aims that it sets out for itself in a planned way, the potential that depends on the number, composition, condition and growth of population, on energetics, reserves and extraction of raw material, level of industry, agriculture, transportation communications, and public services; as the results of space advances this potential will become practically unlimited. A single world economy extracting from the natural resources of the moon and other cosmic body raw material and energy will avoid terrestrial limitations. Limits to the use of atomic and thermonuclear energy and all other sources of energy will disappear.

Integrated automation of industry and agriculture, transportation, communications, daily services, planning and recording, and scientific research will make physical and mental labor easier. There will be enough leisure and enough time to engage in scientific and artistic creativity, sports, and tourism. Mankind will carry out gigantic transformations of his native planet, will transform deserts, jungles, taiga, and polar regions into inhabited fertile lands, will learn to regulate /324
the weather, and to improve the climate at the equator, in the arctic, and in the antarctic.

Mankind will do away once for all with hunger and impoverishment -- these are the first invariable conditions for the beginning of the space age. People will work with awareness, without feeling coercion, including economic coercion, for labor for them will be transformed into a natural requirement in society concentrating the efforts of all mankind to achieve common goals requiring quite inevitably the entry into space and the mastery of its treasures.

Changes in social consciousness that the mastery of space will bring about are by no means limited just to the legal and political sphere. As we have already noted, tremendous revolutionary shifts will occur in all the sciences. The possibility of establishing astronomical instruments outside the earth's atmosphere, on artificial satellites or on the moon, will multiply by many times the size of the part of the universe that we can observe; and because of this many thus-far unsolved problems in astronomy, physics, chemistry, and geology will be solved, and it is very possible that new phenomena and regularities will be discovered. And what applies to the megaworld will also occur with respect to the microworld: physical laboratories on satellites will make it possible to study using cosmic rays of super strong energies regularities of the world of elementary particles unattainable for earth accelerators.

The landing of man and automatic craft on the moon (just as the actual space flights) is producing powerful stimuli for advances not only in the science of inanimate nature, but also for biology, psychology, and medicine. These sciences must above all investigate the behavior of astronauts in unfamiliar conditions of high acceleration and the absence of gravity during flight, consequences that show up upon return to earth, and the possible genetic aftereffects of cosmic irradiation. Further, they will have to study the condition of the human organism and /325
the mind in circumstances entirely different from terrestrial which will be encountered by personnel who will assemble in space re-launching stations and will work on them, or else will build on the moon and other cosmic bodies bases with artificial conditions and will maintain them. Finally, the sciences must take up the upgrading of man -- improvement of his hereditary disposition, and upgrading of his qualities, both physical as well as (by means of psychology and pedagogy) spiritual. The mastery of space will assist in solving the puzzle of the origin of life and in carrying out artificial synthesis of even the simplest living organisms.

The discovery of new facts in space biology will possibly accelerate the elimination of various diseases. The mean longevity will be raised to 100-12′ years, to an age when death, as was foreseen by the great Russian physiologist I. I. Mechnikov, may perhaps no longer frighten and depress man.

The space age of mankind, the pathway to which is at the same time the pathway to a classless communist society, will alter not only the content of science. Science will cease to be a pursuit only of one social group; it will become a people-wide pursuit and the broad masses will master it.

The materialistic understanding of nature, which was one of the essential conditions that made the birth of astronautics possible, will ceaselessly become more profound, enrich and correct some of its premises, and replace them with new premises, by improving its method of cognition -- materialistic dialectics.

To no less an extent, and perhaps even to a greater extent than science, art will become a mass activity in the space age. By being freed of concern over output and with enough leisure, the man of the future will be able to broadly develop his artistic talents. Improved means of communications -- color television, stereoscopic films, and others -- will make any work of art /326 available to everyone. People in the masses will not only begin to love art, but also to create it.

The mastery of space will familiarize man with a new environment, will rouse emotions new to us, and will introduce into art new content and new forms. And technology of the future will give to the new art new facilities for externalizing its images: it is possible that there will be acoustic paints, dynamic sculpture and painting that alter their shapes, symphonies of odors, and so on. But in whatever way this art of the future will be different from what has been achieved today, we are sure that it will reflect reality in lovely images, objectively, materialistically, and thus satisfying the optimistic social awareness of its age.

What kind of people will these be who will live in the "space tomorrow"? It will be easier for man to learn about the world around him than about himself. Here we can only advance several of the most general considerations about the future of man, and rather about what he will not be than about what he will be.

Since the breeding-ground of all vices -- the commodity economy with its buyers and sellers, and the inequality of economic and social status of people -- will disappear since all people capable of productive labor will steadily participate in it, all manifestations of the dog-eat-dog principle and private-property egotism will be forgotten. Man will become truly humane and will be able to harmonically combine personal and collective interests.

This will be a man that is comprehensively and profoundly educated, thinking strictly logically and boldly, strong and tough, attractive and art-loving, skillful and just, and indefatigably overcoming all obstacles in his path.

This man of the future is already being shaped today, there-we can all count ourselves as among the creators of the future space age.

SPACECRAFT OF THE FUTURE /327

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In all the history of mankind and even, perhaps, in any foreseeable future one cannot find an achievement that is close to interstellar space flight in scope. But such a flight will take place; it cannot fail to by the very logic of the development of human society, by the virtue of the profound fundamentals of the creative nature of man.

In fact only on planets of other suns can we encounter representatives of another, perhaps, more developed civilization. And even though communications with such civilizations using electromagnetic, gravity, neutron, or any other kind of waves that nobody knows about yet will probably be established somewhat earlier than the stellar expedition will be organized, only an expedition will be able to make personal contact and in fact nothing can replace it.

We can imagine to ourselves also a situation when a stellar expedition will be a forced alternative to the destruction of earth civilization, for example, owing to catastrophic changes in the trend of thermonuclear reactions on the sun or its gradual cooling. In this case no longer would it be a small handful of enthusiasts, but now thousands and thousands will be carried away on space flights to the location for "re-siting" the earth civilization, which will probably be some as yet unsettled, but life-suitable planet of another sun. True, there is every reason to assume that this alternative can arise only after billions of years, so that long before that numerous stellar expeditions to different parts of our galaxy will have been carried out.

But even the very first stellar expedition is an undertaking in the very remote future. So remote that to some talk about this expedition is clearly premature, especially from the engineering standpoint. But the entire experience of the growth of science attests to the exceptional importance that the sequence of thought somewhat outpaces the sequence of actions, and in this is the price of scientific progress.

And so, a stellar expedition as an engineer would conceive of it. The success of the stellar expedition, just as the solution of any engineering problem, depends above all on the proper formulation of the goal. First of all, where to go? What star should be picked as a target?

Of course, this star must be as close as possible to us, for distance is the principal obstacle on the path of the stellar expedition. But it need not necessarily be the closest star, the distance to which is somewhat more than 4 light years (recall that 1 light year corresponds to $9.45 \cdot 10^{12}$, or about 10,000 billion km). In fact the number of very near stars, the distances to which are of the same order of magnitude, are not so few. Within a sphere having a radius of 100 light years and with its center at the sun there are tens of thousands of stars. Let us reduce the radius of the sphere by a factor of 10, that is, down to 10 light years, but even then within the sphere will be included still 7 stars, and for a radius of 11 light years -- another 5 stars (there are 53 stars in a sphere with a radius of 16 light years); and these are already discovered stars; and so it is altogether possible that there may even be others. Just what star should we choose? /328

As planets move around the sun in their annual cycle, so also the sun with its planets has its "galactic" year in nearly circular movement about the center of the galaxy at distances of about 32,000 light years from it. True, the duration of this year is much longer; of course, from our vast galaxy we cannot expect the mobility like the one which the solar system, that is a miniature of our galaxy, possesses. For the sun one galactic year is about 300 million ordinary earth years, even though the sun travels in its orbit almost 10 times faster than the earth: the orbital velocity of the sun in this movement is about 230 km/sec.

It appears that at such a high initial velocity of motion a starship must necessarily be used, which then determines the optimal flight trajectory, as in the case of interplanetary flights within the solar system. However, actually the orbital velocities of the sun and the star that is our destination are virtually the same, therefore the distance between them is negligible relative to the scale of the entire galaxy. Therefore, even though strictly speaking the trajectories of interstellar flight are also Keplerian orbits (if, of course, Newton's law is valid also in the scale of our galaxy), they are virtually the same as straight lines, so that a flight to any of the stars neighboring the sun can be regarded as rectilinear. Here already we observe a familiar rule, which is that the shortest path is a straight line, while in the already mastered near-solar space this rule is not at all operative. As we can see, even an interstellar flight has its advantages, although they pale compared with the innumerable difficulties...

Thus, the direction does not matter (here we neglect the intrinsic velocity of the sun relative to the "fixed" stars, equal to about 20 km/sec; naturally, in exact calculations it must be taken into account). But what then determines the selection of the star?

This question can be answered at once: of course, the possibility of contact with an alien-planetary civilization. In fact it is precisely this that is the main stimulus for the interstellar flight. If one could establish the presence of intelligent life on one of the planets of the nearest stars, selection of our destination would be predetermined.

It is not precluded that the nearest stars accessible to our expedition will not be foci of intelligent life. This would be a great disappointment, but even in this case we cannot doubt that the expedition still will be arranged. In fact the simple detection of life on a planet on a remote star, even if not intelligent, but different and not similar (perhaps, even similar!) to terrestrial life would have enormous scientific importance. Furthermore, even if the planetary system of the star proved to be entirely devoid of life, even then the scientific value of the expedition will be inestimable, for science will finally obtain data on one more planetary system besides the only one known to us. This probably will permit the most valuable cosmogonic conclusions about the formation of stars and planetary systems. It can be suggested that even in the worst of cases, even if all the nearest stars proved to be lacking planetary systems, the stellar expeditions still would be carried out. The striving of mankind to learn about nature is unlimited. /329

Of course, the situation would change in the event of new revolutionary scientific discoveries that would make flights even to more remote stars realistic -- at that time we would already probably select a "civilized" planet.

But for the moment we must determine the situation on the nearest stars. Even today there is every reason to suggest that there exist planetary systems at at least two (some believe even at seven) of such stars: in 1960 the presence of planet-like satellites (or a satellite) was found at the star Lalanda 21185 in the constellation Ursus Major at a distance of 7.9 light years, and in 1963 -- at the Flying Barnard star in the constellation Serpens at a distance of 5.9 light years (it is called flying owing to the extremely large intrinsic velocity, amounting to 140 km/sec). Based on the latest observations by American astronomer Van de Camp, not less than three planets whose masses are 200, 300, and 400 times greater than the earth's mass revolve about the Barnard star.

As we know, the presence of the satellites has been established from the negligibly small perturbations in the motion of the star itself, the only reason for which could be satellites. Therefore we cannot state that only one satellite exists in this case; it is quite possible that each such star has a developed planetary system like the solar system.

One of the first scientific tasks to be carried out in the preparation of the stellar expedition is therefore the attempt at directed experimental detection of planets at the nearest stars, and even better -- inhabited planets, that is, with a developed biosphere, not to speak of the possibility even of the direct detection of intelligent life.

Achieving this goal is possible given conditions of the tremendous progress made in observational astronomy and astronautics. It requires supersensitive astronomical instruments located on the moon or even on satellites of the outer planets, gigantic radio telescopes, radars and lidars (laser locating facilities), and so on. Perhaps it may be required to send a number of interstellar automatic space satellite probes in order to cover most of the trip to the star and perhaps even reach it, and reporting back to the earth about everything seen. Before the beginning of the expedition as much as possible must be learned about the destination planet; its size, atmospheric composition, temperature conditions, presence of water, and so on must be established.

Now we come to the most important problem of the interstellar expedition -- its energetics. How much fuel must be stored on the starship to carry out the expedition? How are communications to be maintained with this starship? In general, is such an expedition possible from energy considerations?

The required fuel reserve on the rocket needed to make the space flight is estimated by the so-called characteristic velocity, taken into account energy outlays at all flight segments. Thus, for example, in a flight to the moon, landing on it, and returning to the earth, the characteristic velocity can be 20-25 km/sec, and for a flight to Mars -- 30-35 km/sec. What is the minimum characteristic velocity for a flight to a star at a distance, let us say, of 5-10 light years, with landing on a planet of this star and return to earth? /330

To overcome the gravity field of the earth and the sun, the rocket must be given the third space velocity, or the escape velocity of 16.7 km/sec. This same velocity must be overcome in the return to earth, which will be a total of 33.4 km/sec. If it is suggested that at the endpoint of the flight trajectory, that is, at the planet that is the destination, the same gravity field as at the beginning of the flight has to be overcome (this is quite applicable for our illustrative purposes), then another 33.4 km/sec must be added. Gravitational, aerodynamic, and other losses, as well as maneuvering, correction of trajectory, and reserves will require approximately an additional 10 km/sec. Thus, overall we get about 73 km/sec. However, we can greatly simplify the problem if we use the concepts of K. E. Tsiolkovskiy on refueling in orbit and aerodynamic braking during landing; by this technique one can reduce the characteristic velocity by approximately 30 km/sec -- and then 43 km/sec will remain. This is only about 1.5-2 times more than for a lunar expedition.

The well-known Tsiolkovskiy formula ($v = 2.3\ w\ \lg N$) shows that even the rocket engine gas exhaust velocity already attained at the present time, w, equal to about 4 km/sec, the above-indicated characteristic velocity v = 43 km/sec corresponds to the Tsiolkovskiy numbers N equal to about 100,000. This means that the weight of the rocket structure and payload, that is, of the starship and crew will be only one-thousandth of a percent of the launch weight of the rocket, and all the rest will be fuel.

This appears to be an insurmountable barrier on the journey to the stars -- building a rocket with a Tsiolkovskiy number of tens and hundreds of thousands is impossible.

How then can this barrier be overcome?

The basic approach is shown by the very same Tsiolkovskiy formula. Obviously, we must in every possible way increase exhaust velocity w. Chemistry, as we know, is already virtually helpless to assist here in any substantial way -- the attainable exhaust velocity of 4 km/sec is very close to the maximum possible for chemical rocket engines.

Resorting to nuclear energy in this case is quite natural. Can nuclear rocket engines of starships be built? Will they permit the launching of a stellar expedition?

If one imagines a rocket engine in which the ordinary combustion chamber is replaced with a uranium or plutonium nuclear reactor, where the nuclear fuel intensely heated owing to the chain reaction of atomic fission escapes from the engine producing a jet stream, then this engine's exhaust velocity can be /331
as much as 20,000 km/sec. An increase compared with chemical rocket engines of 5000 times!

But building a nuclear rocket engine like the one described is virtually impossible; the reason lies in the tremendous stellar temperatures that are inevitable in this kind of engine: They are as many times greater than the gas temperature in an ordinary chemical rocket engine as nuclear energy is greater than chemical energy. Or else the engine thrust has to be reduced to such an extent that it becomes senseless.

True, there is a way of reducing temperatures in an engine -- this necessitates diluting nuclear fuel with some other, inert substance that has no relationship to nuclear reaction, for example, hydrogen (this is best of all). Then the heat given off in the engine will be expended in heating the bulk of the substance and the temperature will be reduced. But so will be the exhaust speed. In the best of cases when the nuclear fuel and the inert substance diluting it are in the reactor core in a gaseous form (here restrictions on temperature associated with the ordinary solid core, for example, uranium-graphite as in existing stationary and mobile reactors, are eliminated), the exhaust velocity can be as much as 30-300 km/sec. True, such gaseous reactors have not yet been built and building them is not simple.

Still greater are the potentialities of thermonuclear rocket engines based on thermonuclear synthesis, but such engines do not yet exist and even the very problem of a controlled thermonuclear reaction has not been solved.

Foreign experimental nuclear rocket engines employ a scheme in which a reactor with a solid core at a maximum working temperature of 2500-2700° C is used. When fueled with hydrogen as the working body, the exhaust velocity in these engines is 8-10 km/sec. Even this increase of 2-2.5 times compared with ordinary chemical engines leads to a reduction in the Tsiolkovskiy number from hundreds of thousands down to hundreds. Building such space rockets is already within the capabilities even of modern rocket technology. Does this mean that a stellar expedition is also within our grasp?

No, unfortunately. The fact that the characteristic velocity presented above was determined by us as the minimum necessary for an interstellar flight. In particular, in its calculation we took account of the minimum velocity that a starship must acquire in its launch from earth, namely the escape velocity of 16.7 km/sec. This velocity is actually sufficient to overcome the field of solar gravity and to travel to any star, but this interstellar flight will take place at a negligibly slow speed, since all the kinetic energy imparted to the starship by its engines during the launch will be expended in overcoming the force of solar gravity.

But even if it is assumed that the starship velocity beyond the limits of the solar system, that is, over the main segment of its trip, will be several kilometers per second (to achieve this, the takeoff velocity will have to be appropriately increased, and then naturally the characteristic velocity rises). /332 Then the ship will be enroute to the nearest star roughly 100 times longer than a ray of light travelling the same trip. Just a one-way flight will take hundreds of thousands of years! And back again will take just as long.

We have encountered another aspect of the energetics of a stellar expedition -- the necessity of radically shortening the flight time and as a result of this, a corresponding increase in the energy outlays in performing the flight.

Of course, one can imagine a stellar expedition lasting hundreds or even thousands of years, so that only the distant progeny of the astronauts will return to the earth, knowing about it only from legends transmitted down from generation to generation, or even from hopelessly outdated books and films. But is this prospect really the only one?

If we take as the maximum allowable length of a stellar expedition corresponding to the active life of a single generation, so that astronauts will return to the earth who had taken off from it, the expedition must last not more than 30-40 years. This means that the starship velocity must be 0.2-0.3 times the speed of light, that is, 60,000-90,000 km/sec. Obviously, here the characteristic velocity must be enormous -- 150,000-200,000 km/sec.

Thus, only future thermonuclear rocket engines, when they will be built, will be able to make the prospects of a stellar expedition realistic. It is suggested that an escape velocity of the order of 0.1 times the speed of light can be achieved in these engines, that is, 30,000 km/sec. At present we cannot say precisely when this will occur. If we assume a starship flight velocity of 0.3 times the speed of light (the acceleration to such a velocity during liftoff and deceleration during landing can also be easily allowed for), then as shown by approximate calculations, the Tsiolkovskiy number for the starship must be several hundreds. This is feasible in principle, though it does represent an engineering task that is unprecedented in difficulty. So if we assume the weight of an empty starship (including payload in the form of a spacecraft and crew) to be hundreds of tons, the fuel reserve on board the launched starship will be hundreds of thousands of tons.

The most logical way to reduce this reserve lies in a further increase in the gas exhaust velocity from the starship engines. Modern science knows of at least one realistic way of this increase -- use of so-called electrorocket engines. In these engines the acceleration of a working body producing the thrust of the jet will be achieved not because increased pressure is produced within the engine, as in ordinary chemical or nuclear rocket engines. Here powerful natural forces -- electromagnetic forces -- will operate.

Of all the known and long-since investigated types of electrorocket engines, two appeared to be entirely suitable for the purposes of a stellar expedition -- electrostatic (ionic) and electromagnetic (magnetohydrodynamic, or plasma). In the first /333 case the working body is ionized ahead of time, and then is accelerated in an electrostatic field: in the second -- acceleration of the plasma forming in the engine is carried out by exposure to an electromagnetic field. In engines of both types, the exhaust velocity can be very high -- from 0.5 times the speed of light or even higher. Using fundamentally the same methods, elementary particles in experimental devices have been accelerated to velocities close to the speed of light.

Electrorocket engines require superhigh capacity power plants on board the starship to supply electric power to the engines. Obviously, these power plants can be only nuclear. This then is the main disadvantage of electrorocket starships -- the dimensions and weight of the on board power plant proved to be extremely large; in fact its required capacity can be many times greater than the biggest hydroelectric power stations. And the effort to reduce this power will lead to abrupt reduction in the engine thrust, all the way down to several grams instead of the thousand-ton thrust of ordinary engines.

Even with reduced thrust the stellar expedition, it is true, will still prove possible, no matter how strange this statement appears considering the tremendous liftoff weight of the starship. In fact, the starship will have already been launched from outer space from some launch orbit, where it will have first been inserted by powerful ordinary rockets or where it will have been assembled. And when launched from orbit, when the starship already has attained the first space velocity, any, even the weakest thrust will increase its velocity. Of course, if this force is small, as in the case of electrorocket engines, then the ship acceleration will prove to be very small, so that during acceleration to the enormous velocity below the speed of light the starship must be accelerated for an extended time. However, the total flight time in this case will be so long that it will be sufficient both for the acceleration as well as for the braking at the end of the flight. And perhaps, in general the starship engines will not be shut down altogether in this case; only at first must they accelerate the ship, and then decelerate it. Incidentally, continuous operation of the engines will solve yet another important problem associated with the harmful effect of prolonged weightlessness on the starship crew.

Of course, this is not at all similar to the operation of modern rocket engines which are switched on only for measured minutes, but potentially electrorocket engines are capable of very long operation; they have already been tested in the laboratory in continuous operation for many days. True, in days, and not decades, but even these engines are not at all yet like those needed for the starship, but actually no one has yet even begun preparing for the stellar expedition....

Electrorocket engines have another major disadvantage -- they need an on-board power plant; but rejected heat, inevitable for this kind of plant, can be removed only into the ambient space. Since the capacity of the starship power plant is very great, likewise the amount of rejected heat that the starship radiator must emit into space will also be great. Therefore, this radiator will prove to be enormous in size; it must have /334 emitting plates hundreds of square meters in size.

Major design and operating difficulties are involved in building the radiator. It weight will also be sizeable. The weight of the on-board power plant with the radiator, and also the required weight of the nuclear fuel will be the Achilles' heel of the starship using electrorocket engines. But still building such a starship is one of the possible engineering solutions to the problem of a stellar expedition.

Essentially this is the limit to the real possibilities of solving the problem of stellar expeditionary energetics from the standpoint of 20th century science and technology. But this expedition in fact will not be carried out in our century.

Are there no other, more radical solutions to this problem that would even theoretically be provided by present-day science with allowance for possible scientific achievements of coming centuries?

First of all, what are the limiting possibilities for increasing the exhaust velocity of starship engines?

We know that a maximum possible velocity is the speed of light. Obviously, it is this that must be the exhaust velocity from an ideal starship engine. But only light itself is propagated in nature at the speed of light; quanta of light, photons in an absolute vacuum, travel at this velocity. Therefore, the "ideal" engine then must be a light, quantum, or photon engine, as it is called.

Usually a starship is depicted in the form of this kind of quantum, or photon rocket. The "working body" in it is not particles of a material, but photons; the jet stream is converted into a beam of light, the rocket itself into a unique superpowerful projector. This rocket can be accelerated into space up to as high a velocity near the speed of light as we wish, but even in principle science thus far does not know how it can be built. There are many unique difficulties along the way, but the biggest one lies in the absolute necessity of an ideal, that is, without any losses, formation of a superpowerful reactive beam, while thus far science has been able to generate quite powerful light beams only at lower efficiencies. This is the case, for example, even for a laser, which in another respect, in particular in the sense of attaining high intensity and ensuring high beam directivity, that is, the absence of light scattering, would be custom-made for a quantum starship.

The requirement of an efficiency equal to unity or at least very close to it is likely the most important for the engine facility of a starship of any type. This requirement can be readily understood if we recall the scope of the energy outlays in executing an interstellar flight. In order to reduce to a minimum the required stores of working body on board the starship, its potential energy must be utilized completely. However, we know that this necessitates the complete transformation of the material into radiation according to the Einstein equation, $E = m \cdot c^2$, that is, annihilation of matter It turns out that in principle this complete utilization of all energy capabilities of matter is possible only in a photon rocket. It is precisely in this that its theoretical importance as an ideal starship lies.

Unfortunately, although the process of annihilation is familiar to physicists not only theoretically, but experimentally, ways of utilizing this process in energetics, in particular in a photon rocket, are thus far unclear even in principle. We cannot say that this in general will be achieved at some time. Therefore building and annihilation photon engine is thus far only a "pipe dream" of astronautics. /335

In searching for solutions to the energy problems of a stellar expedition, scientists have also given thought to the possibility of using the energy reserves of the interstellar medium. This principle is well known to energetics. On it is based the operation of steam engines, internal combustion engines, and air-breathing jet engines. True, in all these heat engines the potential chemical energy of the medium is used (namely, atmospheric oxygen), while in the case of the starship we have in mind to the use of the total potential energy of interstellar matter in annihilation rocket engines. But essentially both processes are similar.

If we digress from the fact that an annihilation engine has not yet been built and at present we do not know in general whether it can be built at all, no other problems of the same magnitude are involved with realizing the idea of building a kind of "ramjet annihilation" engine. But the value of its use in a starship is determined by what the density of interstellar matter is, and how much of this material the engine can absorb and consume per second.

From various estimates, the density of interstellar matter averages about one particle per cm^3 of space, where we are referring both to individual atoms and molecules of matter, mainly hydrogen (about 99 percent of the total amount), as well as dust particles (possibly particles of ice and graphite).

We can easily see that at the interstellar ship flight velocity of 0.3 c (which we adopted above), every second $9 \cdot 10^9$ particles of matter will pass through each cm^2 of any area of the kind of "air intake" of the starship, that is, a device absorbing head-on particles of matter, for their subsequent use in the annihilation engine. In spite of the quite large absolute value, it is still not very large if we recall that in normal atmospheric conditions, 1 cm^3 of the air around us contains $2.7 \cdot 10^{19}$ particles -- gas molecules. In order for same amount of particles to pass into the starship engine in 1 second, the area of the particle receiver -- the space "air intake" must be, evidently, $(2.7 \cdot 10^{19})/(9 \cdot 10^9)$, or about $3 \cdot 10^9$ cm^2 (that is, one-third of a square kilometer!).

As we can see, the surface area of the receiver must be very large. However, it is not here that, of course, the heart of the problem lies -- we can even build such a receiver. But how must it be arranged? No one yet knows this....

Incidentally, if we are speaking about finding a working body for starship engines in space, we cannot but recall suggestions of using for this purpose not the microparticles of the interstellar medium, but large celestial bodies, for example, asteroids.

We can select a suitable asteroid of sufficiently large size, moor it to the starship, and use the matter of the asteroid as the working body for the annihilation engine. /336

We can also recall several radically new ideas in this field associated with the latest achievements in physics. These ideas consist in an attempt to convey the required energy to the travelling starship from without, using the new theoretical possibilities of energy transmission at a distance. In one case using a laser beam has been proposed, and in another -- a flux of superhigh-frequency energy.

Some recent scientific data suggest that for very powerful concentrated energy bursts there is a practically complete absence of dispersion when propagated in space can be achieved. This in principle will permit the transmission of considerable amount of energy to a travelling starship at very great distances using auxiliary cosmic power stations or else using special energy-relay lines. As a modification of this remote energy supply approach, we can also recall the possible use of the "sail effect," when instead of the ordinary reactive principle of starship acceleration (which generally speaking become energetically disadvantageous at high velocities below the speed of light), a large sail surface is mounted on it, receiving the active pressure of the radiation beam. Driven by this "laser wind" the starship can reach very high velocities.

All such projects of course do not yet have serious engineering foundations.

The more remote the star to which the starship is heading lies in our galaxy, the more difficult becomes the problems of stellar expeditionary energetics, if we have in mind of course its acceptable overall duration. Extra-long flights over distances of hundreds and thousands of light years involve an expedition lasting many millenia. The engineering problems of such an expedition are simply inconceivable, not to speak of the psychological, biological, and other kinds of problems.

However, science knows one fundamental possibility of making the longest stellar expeditions for any practically conceivable time as short as we wish, not longer, for example, than 2-3 years that would be needed at the present level of the development of astronautics for a flight to the planets in our solar system closest to the earth -- Venus and Mars. This possibility is entirely theoretically beyond question, since it is based on Einstein's special theory of relativity.

According to this theory, the passage of time on a starship travelling at a speed near the speed of light will be slowed down the more strongly, the closer this velocity is to the speed of light. Therefore the actual time of the astronauts measured by a clock in the ship or by any other physical, chemical, or biological processes on the ship, will not coincide with earth time. By the moment the starship returns to the earth, the difference in the clock readings will persist -- the starship crew will prove to be younger than if it had remained on earth. Twins, if one had flown to the star, would now be at different ages, and the difference in age may be very great. For example, if the starship velocity was 87 percent of the speed of light, then a clock on it would travel half as fast as on earth, and for a flight velocity differing from the speed of light by only 2 cm/sec, the time on earth would proceed 86,400 times faster than on the starship. A second on the ship would correspond to a day on earth. /337

The so-called paradox of twins in principle permits carrying out, during the lifetime of one generation of astronauts, expeditions as long as we wish, even to the most remote of the known quasars, of the order of 10 billion light years. Only velocity is needed to do this. In principle, the starship can be accelerated to any velocity as close as we wish to the speed of light. This requires only energy. But astronautics is not in a position to do this, and not only today, but also in any foreseeable future. This makes a relativistic stellar expedition only a fascinating dream....

But the passage of time in principle can be "slowed" for astronauts by another means, not complicating the energy problems of a stellar expedition that are already tremendous, but rather by simplifying them. This is a biological approach.

Actually, if it is not possible to use the effect of relativistic slowdown of time on a starship and, this means, a corresponding slowdown of all biological processes and the organisms of astronauts compared with the same processes in people on earth, then why cannot these processes be modified, by achieving their abrupt inhibition?

Science knows of natural examples of this kind of inhibition, in particular, examples associated with the winter hibernation of animals and other related adaptive phenomena -- so-called anabiosis. In some unfavorable conditions of existence, for example, exposure to reduce ambient air temperatures, in some animals the intensity of living processes is severely reduced. Then, when favorable conditions again begin, normal intensity of life activity is restored. Anabiosis can be reproduced also artificially. This was first achieved by the Russian biologist P. I. Bakhmet'yev (he experimented with flying squirrels). /338

Cannot a starship crew undergo artificial anabiosis? Using anabiosis, "biological" time onboard the starship would be severely slowed for participants in a stellar expedition, and in the ideal case it would be altogether halted. This would in principle open up the possibility of carrying out prolonged stellar expeditions for the lifetime of one generation of astronauts. At the same time the task of life suppo' , for the starship crew during the flight would be appreciably simplified.

But thus far there are no appropriate theoretical treatments of this problem and no experimental research. But still, tremendous vistas for astronautics may be related to anabiosis. It is not precluded that precisely here we have the key to a stellar expedition. Incidentally, solving the scientific problem would have tremendous long-range consequences not only for astronautics alone, but also for biology and medicine.

Since we have been talking about biology, we must say something about general medical-biological problems of a stellar expedition, which are prehaps no less essential than the problems of energetics, although not as obvious. The main thing in these problems that differentiate them from similar problems in modern astronautics is involved with the unusually long duration of the flight, which entirely removes the possibility of building up required reserves -- food, water, and oxygen -- onboard the ship as it now been done.

The only suitable solution lies in building a closed ecolcgical system onboard the starship, simulating the natural turnover of matter on earth and modifying it only in a number of respects. This system must be a complicated biotechnical complex incorporating both biological links -- plants and animals (lower and higher), as well as complicated technical facilities carrying /339 out the most important working processes ensuring prolonged functioning of the entire system, and regulating and sustaining its optimal working regime. This system is called upon to provide completely for the conditions of starship crew viability -- optimal composition and parameters of the atmosphere, providing varied foods and water, using for this purpose wastes from the crew and the biological links of the system itself and not permitting the cumulation of any waste materials, that is, not allowing any so-called blind alleys to be built up from which material cannot be recycled into the system.

The starship life support system must function reliably and trouble-free for decades, and the redundancy of system components must be reduced to a minimum. This poses completely unprecedented problems with respect to the reliability and optimization of the system "man-machine", which of course applies to all other systems and facilities of the starship, and perhaps major difficulties for the engineers building the starship will be associated with tackling precisely this problem.

It is interesting to note that even in the future when advances in science will make it possible to successfully replace natural food products without artificial, as well as many truly biological processes -- with more efficient physico-chemical processes, still the role of biological components of the starship viability system will always be very large if only due to the need to provide onboard the starship an environment customary to astronauts.

There is no doubt that organization of a stellar expedition would require enormous mobilization of all efforts and resources of human society. It will be within the capability of the future, happy communist mankind, firmly established without precedent.

SPACE FOR MAN /319

K. P. Feoktistov, Cosmonaut-Pilot of the
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Thus far only the reconnaissance of space has begun. Therefore we must think about the future. Today it is even difficult to imagine all of the tremendous volume of scientific research and technical feats necessary to master space.

Ahead we have to build equipment and instruments for methodical study of the conditions awaiting man in interplanetary space (solar flares, dust clouds, meteor showers, and weightlessness). Complicated automatic facilities for studying the planets in our solar system are to be built. These facilities will make it possible to obtain data on radiation and technical fields, on the atmosphere, on the nature of the surface, on the biosphere if it exists, and so on. All this is necessary for successful manned flights to planets and their satellites. Large spacecraft must be built for journeys of many years to the planets. They must be provided with equipment for ultra-long communications and navigation, power facilities, and means for providing the crew with oxygen, food, and water. To achieve these goals, new fields of science and technology must be pioneered and old /320 fields (and they have already now been founded and developed), such as cybernetics and the technology of electronic computers and analyzers without which building spacecraft of the future is inconceivable; planetology (an old science, but one that today is seemingly been born anew); facilities for investigating planets by direct and indirect methods; the science of the sun and sun service facilities, possibly with circum-solar automatic satellites, whose data can be used to observe and predict "solar weather" (flares, their numbers, intensity, direction of radiation fluxes, and so on); space biology and medicine; and also human life support techniques for flight conditions.

Finally, it is required to solve problems not only in mastering planets in our solar system, but also in building up observatories and stations for artificial planet-settlements in space that would enable expanding and deepening investigations of the universe, broadening the human sphere of life, and also providing for trips to the stars.

Achieving these goals requires tremendous efforts from mankind. Often we have occasion to hear various skeptical remarks concerning the usefulness of these efforts.

Some, for example, say: "The mastery of space is of course interesting. But why do we, our generation, need it? Well, people will live in space perhaps only after a thousand years and does it make sense to put forth efforts and funds today when there are many on earth who lack food, clothing, and shelter? Well then, let us first improve life on our planet, and space can wait (and perhaps, will never be required!)". /321

Others say: "Space, human progress, and the extension of the sphere of human life, will all this come about? In fact, in our time the world is in a very unstable condition. Given modern means of annihilation that are in the hands of various governments, will not mankind in the very near future find itself in a catastrophic nuclear war and in the destruction of civilization? But even if war was in fact prevented, where will progress lead?" They reason further. "Even today it is clear that scientists acting methodically can make artificially (possibly from inorganic elements) creatures of a higher intellect than man capable of living in a broader range of environment conditions. Even if "blind" nature had been able to build man by the "trial and error" method, the consistently logical work of scientists will inevitably make it possible to design a creature more intelligent and better adapted to life. And people will /322 unconditionally be doomed to "degeneration": with the "saturation" of knowledge about the surrounding world, interest in it will fade; with improvement in living conditions and in safety, man's viability and will to struggle for existence will become weakened, and before mankind masters space it will be displaced by automata better adapted to life."

Generally speaking, it is much easier to raise doubts than to resolve or refute them. However, let us think about the subjects which have been given here.

There is no need to try to predict the future of mankind for a thousand years. The problem of mastering space is the problem of our time. We cannot, on opening up the door into the new world, at once slam it shut. We cannot stop our forward advance. And even though the main importance of space investigations in our time lies in the fact that they are laying the pathway into the future, and are opening up new spheres for mankind, these studies will be and already are of practical importance to us.

Advances in space research, realization of complex programs of building space launch vehicles and automatic space stations as well as spacecraft will lead to a vigorous growth of the /323 new fields of science and technology. And results of this development are showing up in ordinary "earth" life and are finding application in the fields of science and technology that pursue entirely "earthly" aims. This, so as to speak, is the indirect influence.

Some advances in space technology even today are beginning to enter directly into everyday life: relay satellites are broadening the capabilities of communications and television, navigation satellites are improving reliability in navigation in the oceans, and weather satellites make it possible to greatly improve the weather service on earth. Penetration into space and its mastery by mankind is a matter not of the remote, but of the immediate future. We cannot counterpose efforts in investigating space to efforts to improve the standard of living on earth. These are two sides of progress and between them there are no contradictions.

As for the possibilities and danger of thermonuclear war, here there can be only one answer: mankind must apply all efforts to preventing war. It is obliged to do this if we wish to survive.

The question of the "displacement" of mankind by some more intelligent creatures built by it is more complicated. We can raise several objections. For example, does man need to build /324 intelligent "creatures" capable of propagating and sufficiently compact that they will be able to "displace" mankind? Today a negative answer appears more logical. True, one can say that a more rational "machine" civilization at some stage can develop spontaneously and people will not be able to control its progress. But a more intelligent civilization would scarcely be in need of annihilating or displacing another intelligent civilization....

Of course, people will be able to build highly organized, quite compact systems capable of operating over a wide range of conditions in their environment (today we call these automata, automatic interplanetary stations, and so on), but these will be specialized devices intended for investigating the sun, planets, earth and alien-planetary resources and so on. Electronic devices will be built exhibiting a tremendous operational memory and with greater (compared to human mind) capabilities of analysis and processing of data. However, there is no need whatsoever of making these devices capable of self-organization and propagation.

But if at some time people deem it advisable to build and /325 will build a society of "creatures" better adapted to life in the infinite expanses of the universe, then in this case they will be a direct offspring of mankind, a direct continuation and development of human civilization in space.

Doubts associated with the expectation that as knowledge accumulates and with increase in well-being and comfort people will not find new spheres for exploration and research and energy to struggle for their existence ("satiation by comfort and security") appeared to be not serious. Thus far the opposite situation is observed: the more we learn about the universe, the more there is to explore ahead of us, and the more complicated will become the tasks that mankind will encounter, along with newer hazards. It suffices to present, as an example, the problem of flight to the stars. Today practically speaking we cannot see ways of doing this. Can we thus far speak only about the "insurmountable" obstacles and hazards that await man along this path? But nonetheless this task really can be achieved and sooner or later will become within man's power. But then new problems will arise and we can see no end to this.

Mankind is at the threshold of a new era. Let us look around this. The picture is by no means idyllic. In the world there are too many contradictions: tremendous destructive means and political fragmentation of mankind into hostile groups of states, great technical advances of our time, a high standard of living in several countries, along with backwardness, the lack of modern industry, and a low, near-poverty standard of living in other countries. /326

The contradictions have one property in common: they cannot last indefinitely and sooner or later they must be resolved. However, they cannot resolve themselves. An often hard and tortuous path leads to their resolution, but it must be traversed.

Of course, new contradictions will arise. But these now will be contradictions associated with the new way of life, with new problems, with limitations on means available to people, and with the infinitude of the universe. Mankind has come a long way from the Stone Age to our time, the time of socialist transformations. But now we see that ahead of us there lies a yet more complicated and more interesting road into a new world, along which both difficulties and successes await us.

PROJECT FOR TRANSFORMING THE ATMOSPHERE ON VENUS /337

Astrophysicist, Doctor Carl Sagan has proposed a project for transforming the atmosphere on Venus to make this planet suitable for human life. He proposes sowing in the upper atmospheric layers of Venus algae sufficiently tough and productive which would absorb carbon dioxide gas and liberate free oxygen.

Sagan notes that the surface of Venus evidently is an incredibly hot, dry, and quiet desert under a continuously overcast sky. The conditions on Venus are not suitable for life and it is improbable that life could have originated there at any time. Its atmosphere contains considerable amounts of carbon dioxide gas with some water vapor, but has no appreciable amounts of free oxygen. However, it is possible that microorganisms, for example, algae, could exist and multiply in the upper layers of the Venusian atmosphere. Without meeting competition in this lifeless air, the algae transplanted there from earth could grow, propagate, and generate oxygen at a nearly catastrophic speed. It can be suggested that by means /338 of this process the entire Venusian atmosphere could be transformed in several years.

Algae would use carbon dioxide gas and water vapor and would liberate free oxygen. During this process the "greenhouse effect" would supposedly be reduced (trapping by carbon dioxide gas and water vapor of solar heat and preventing its radiation back into space) and the temperature would be reduced.

Since the amount of carbon dioxide gas on Venus would prove to be much greater than the amount of water vapor, direct production of oxygen by algae as a result only of photosynthesis would appear to be inadequate for a considerable reduction in the reserve of carbon dioxide gas. Sagan suggests that this problem can be solved independently. Some of the algae would continuously descend to lower altitudes where owing to heating they would dry up and thus liberate the water they contain. Algae at high altitudes would again utilize this water vapor to continue the process of conversion.

Sagan emphasized that he did not urge that this experiment be carried out if the presence of Venusian life could be established on that planet.

ARE INTERSTELLAR FLIGHTS POSSIBLE? /340

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The problem of interstellar flights, which until recently was an achievement only of science fiction writers, has become a highly fascinating scientific problem. The nearest stars are at distances from the sun measurable at the minimum in several light years, and some of these stars (for example, the Barnard star, Epsilon Eridani, and Tau Ceti) are evidently surrounded by planets. So a starship on which a scientific expedition equipped to investigate one of the planetary systems nearest to the sun would travel must have a velocity close to the speed of light in vacuum in order to be able to return back to earth within the lifetime of one generation. Slow interstellar flights, whose velocities are considerably below the speed of light in vacuum, would be very prolonged and would require either several generations of astronauts or the placement of astronauts in anabiosis, but from the standpoint of modern science would be much more realistic in the future than highspeed interstellar flights.

Let us agree to assume that the interstellar flight will be slow if the maximum starship velocity does not exceed 0.2 c, where c is the speed of light in vacuum. But if the maximum starship velocity exceeds 0.2 c, an interstellar flight is regarded as fast. This division between interstellar flights is of course arbitrary, but it is convenient in our calculations.

The motion of micro-particles at velocities near the speed of light is described, as we know, by relativistic Einstein mechanics in full agreement with experiment. Modern physics has several theoretical and even experimental grounds for assuming that even macroscopic bodies can travel at velocities near the speed of light, and their motion in this case will also be described by relativistic mechanics. Therefore the motion of any starship must obey the laws of relativistic mechanics of a body with variable rest mass, which is a generalization of classical mechanics of a variable-mass body formulated by the outstanding Russian scientists I. V Meshcherskiy and K. E. Tsiolkovskiy.

Note that in the case of a rapid interstellar flight the motion of the starship itself and its jet exhaust obeys relativistic laws. But if an interstellar flight is slow, then two cases are possible. In the first case the motion of the starship itself and its jet stream must be described by classical mechanics, and in the second case -- the motion of the starship itself is described by classical mechanics, but the motion of its jet stream is described by relativistic mechanics. If an interstellar flight belongs in the category of very slow flight, the corresponding starship is converted into a planetship for rapid flights within the solar system.

Today three types of starships are theoretically treated in the scientific literature. The first type, proposed in 1946 by I. Akkeret, can be called a relativistic rocket. The relativistic rocket can be of the thermonuclear (TRR) or ionic (IRR) class. Within a thermonuclear relativistic rocket there are large stores of hydrogen and a thermonuclear reactor in which hydrogen is converted into helium. High-temperature helium plasma escaping through the nozzles of the thermonuclear jet engine produces thrust. Within the ionic relativistic rocket there are large reserves of readily ionized metal (for example, cesium) and an energy source (for example, thermonuclear or annihilational reactor), required to ionize metal atoms and to provide heavy ions for accelerators. A stream of ions exiting from the ionic jet engine nozzles produces the thrust. From the foregoing it follows that relativistic rockets must be of enormous size and launch weight. /341

The second type of starship developed theoretically by E. Zenger in 1956 is usually called a photon rocket (PR). Within the photon rocket are provided large source of matter (for example, hydrogen) and antimatter (for example, antihydrogen), and also a special annihilational reactor in which there is a powerful magnetic field. The presence of the magnetic field leads to the gamma-radiation induced in the annihilation of the matter and the antimatter having a directed character. A stream of gamma-photons escaping through the photon jet engine nozzles produces the thrust. The main advantage of the photon rocket is the maximum possible discharge velocity, equal to the speed of light in vacuum. However, numerous difficulties of a fundamental nature, associated with producing and prolonged storage of enormous amounts of antimatter, and also producing the gamma-photonic thrust, lead to the conclusion that building photon rockets is immeasurably more complicated than building relativistic rockets.

At the present time, based on relativistic mechanics of a body with variable rest mass, a general theory of rockets with single-component and even multi-component jet stream can be formulated. The calculation shows that the following equality is true for a thermonuclear relativistic rocket and a photon rocket with a single-component jet stream:

$$\sqrt{1-\frac{w^2}{c^2}}=1-\alpha, \qquad (1)$$

where α is the ratio of energy liberated in the combustion of fuel to the rest energy of the fuel, and W is the discharge of velocity relative to the rocket, regarded as constant. For a thermonuclear reaction of the transformation of hydrogen into helium, α = 0.0066, so that W/c = 0.115. In the annihilational reaction of matter with antimatter, α = 1, so that by Eq. (1), W = c. Calculation also shows that the following ratio is valid for one of the theoretically possible modifications of an ionic relativistic rocket:

$$\sqrt{1-\frac{w^2}{c^2}}=\frac{1-\beta}{1-\beta(1-\alpha)}, \qquad (2)$$

where β is the fraction of the launch mass represented by the energy source. It can be stated that β does not exceed 0.5. If the energy source is a thermonuclear reactor, W/c is small and amounts to 0.12 when β = 0.5. For the case of an annihilational reactor, W/c = 0.87 when β = 0.5. Thus, using an annihilational reactor as the energy source on an ionic relativistic rocket permits attaining enormous discharge velocities. This circumstance again indicates the importance of a controlled annihilational reaction for the problem of interstellar flights.

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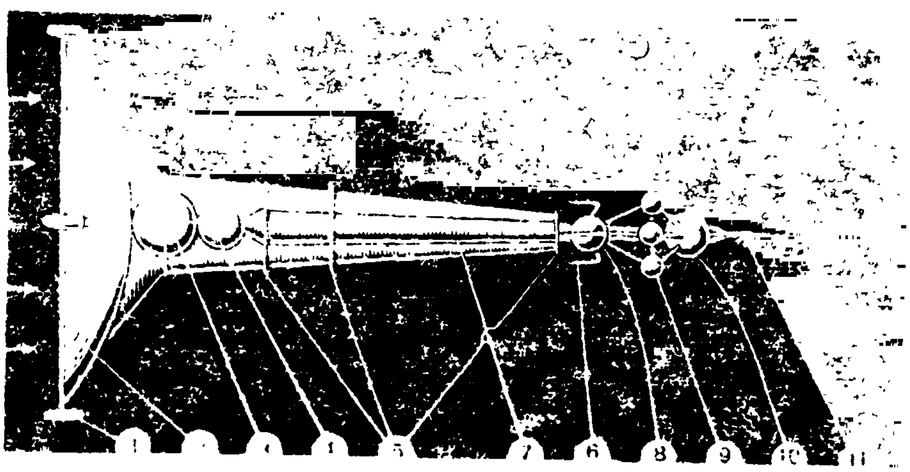

Scheme of a photon starship

1 -- controlled engines
2 -- reflecting mirror
3 -- antimatter storage tanks
4 -- matter storage tanks
5 -- protective shields
6 -- emitters
7 -- main compartment
8 -- astronaut living quarters
9 -- spherical observatory
10 -- central control station
11 -- space rocketplane

Let us look at a multi-stage relativistic or photon rocket as an example, intended for direct and return interstellar flights. The first stage accelerates the starship to the maximum velocity v, and the second decelerates it to zero near the planetary system selected for exploration. The third and fourth stages serve, respectively, to accelerate the starship on its return flight to the same maximum velocity and to decelerate it down to zero near the earth. Only the living quarter section of the starship returns to earth. Let us first assume that all four stages consists only of fuel and that the rest mass of the living quarter-section remains unchanged during the interstellar flight. The relativistic mechanics of a body with variable rest mass enables us to determine the launch mass of this kind of starship. Note that even more realistic calculations can be made that allow for the masses of the structural elements of the stages. Moreover, we can also consider a one-stage relativistic or photon rocket with a living section both for the case of a stage comprising fuel as well as with allowance for the structural mass of the stage.

Calculations show that /343

$$M = m\nu^{-4} = m\left[\frac{1-\frac{v}{c}}{1+\frac{v}{c}}\right]^{-\frac{2c}{w}} \tag{3}$$

where m is the rest mass of the living section and M is the launch weight of the starship. For a relativistic rocket, $w < c$, and for a photon rocket $w = c$, so that it is relativistic as the limiting case.

The table gives the launch masses of a relativistic multi-stage rocket in tons in relation to the velocities w and v calculated by Eq. (3). The rest mass of the living section is taken as 1000 tons, which is not at all too much for an interstellar flight. Note that Eq. (3) is appropriate for the above-mentioned modification of an ionic relativistic rocket only when an annihilational reactor is the energy source. The last row gives the launch masses of a multistage photon rocket determined by Eq. (3) when $w = c$.

Starship	$\frac{w}{c}$ / $\frac{v}{c}$	0.1	0.5	0.9
Thermonuclear relativistic rocket	0.1	$5.5 \cdot 10^{4}$	$3.5 \cdot 10^{12}$	$4.8 \cdot 10^{28}$
Ionic relativistic rocket	0.5	$2.2 \cdot 10^{3}$	$8.1 \cdot 10^{4}$	$1.3 \cdot 10^{6}$
	0.9	$1.6 \cdot 10^{2}$	$1.1 \cdot 10^{4}$	$7.0 \cdot 10^{5}$
Photon rocket	1.0	$1.5 \cdot 10^{1}$	$9.1 \cdot 10^{3}$	$3.6 \cdot 10^{5}$

Analysis of the data given in the table shows that thermonuclear relativistic rockets can serve only in slow interstellar flights, since their launch mass increases very rapidly with increase in v/c (when v/c = 0.9, the launch mass is 6 million times greater than the mass of the earth). In contrast, ionic relativistic and photon rockets are suitable both for slow as well as for fast interstellar flights, where photon rockets are especially attractive since their launch mass has a minimum for a specified v/c. However, from the data in the table it follows that enormous amounts of antimatter are required for photon rockets. Therefore building relativistic rockets in the future appears much more probable, from the standpoint of modern science, than building photon rockets.

Calculations show that allowing for the structural masses, the launch masses rise sharply compared with their minimum values given in the table. For example, when v/c = 0.9, and for a 1000-ton rest mass for the living section, and given the condition that the structural mass of each stage is 0.2 times its launch mass, the launch mass of the entire multistage photon rocket is about 500 million tons, that is, it increases by more than 1000 times compared with its minimum value. Interestingly, for multistage rockets $\delta < \nu$, where δ is the ratio of the structural mass to the launch mass of a stage, which is a constant /344
for all stages. For a one-stage rocket, $\delta < \nu^4$, so that a one-stage rocket intended for direct and return into stellar flights must have relatively lighter structures than a multistage rocket.

Finally, the third type of starship proposed by R. Byussar in 1960 is usually referred to as an interstellar aircraft on analogy with an aircraft on which a ramjet engine is mounted. This starship has shields of tremendous size collecting interstellar hydrogen and directing it into a thermonuclear reactor where the hydrogen is converted into helium. The thrust is produced in the same way as in the case of a thermonuclear relativistic rocket. Since the concentration of interstellar hydrogen averages about one atom per cubic centimeter, the shield of an interstellar aircraft must have huge dimensions so that an interstellar aircraft will certainly be much more massive than a relativistic rocket. The absence of antimatter is a major advantage of an interstellar aircraft.

At the present time the only interstellar medium suitable as a fuel for starships is interstellar hydrogen. The calculations of R. Byussar show that for an interstellar aircraft

$$a = 1.5 \cdot 10^{-3} \alpha \frac{nS}{m}, \qquad (4)$$

where a is the intrinsic acceleration, α = 0.0066, n is the concentration of interstellar hydrogen atoms, m is the rest mass of the interstellar aircraft, which is regarded as constant, and S is the area of the shield. Eq. (4) is valid in the CGS /centimeter-gram-second/ system. Assuming that the intrinsic acceleration is equal to the acceleration due to gravity on earth, n = 1 atom per cubic centimeter, and m = 1000 tons, we find that the circular shield to collect interstellar hydrogen must have a radius of about 1800 km. The monstrous dimensions of the shield in our view preclude its construction even in the distant future. The only theoretical conclusion consists in replacing a material shield with a field shield, that is, in building around the interstellar aircraft powerful electromagnetic fields that would collect interstellar hydrogen and direct it into the thermonuclear reactor. However, even a field shield of this size appears to us improbable.

Thus, from the standpoint of modern science relativistic rockets, and not photonic rockets, and even less interstellar aircraft, are the most suitable for carrying out interstellar flights in the future. Slow interstellar flights are much more probable than fast. Today we must continue developing the theory of relativistic and photon rockets and also the theory of the interstellar aircraft, since this promises much that is interesting. At the same time, we must search for new ways of carrying out interstellar flights. Based on our profound conviction, searching for these approaches must involve studying the microstructure of space and time.

The future will show whether interstellar flights are possible. In any case, at the present time they cannot be regarded as impossible in principle.

ARCHITECTURE IN OUTER SPACE /345

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For the immediate future generations of mankind outer space harbors two tasks -- mastery of space itself and mastery of journeys through outer space to celestial bodies. Associated with the second task, is a third -- mastery of celestial bodies.

If we examine the fundamental novelty of these goals, we must place the first in the primary position. Its achievement must make possible in the future the settlement of living and thinking matter directly in the boundless expanses of interplanetary, and later also interstellar vacuum.

Mastery of this vacuum will doubtless lead to filling it with some kind of material structures or, putting it in more customary language, to building cosmic structures in space of the most variegated forms and most grandiose in size. It can be suggested that in the remote future space will be not the chaotically formed clusters of stars, gases, and other cosmic masses, but in the most precise manner, organized matter regulated by the force of the creative Intelligence engendered by this matter.

It is difficult for present-day man to gaze into a future this remote. But the approach to it even today has appeared so clearly that it is not difficult to imagine the first step along this journey. The steps must lead to the appearance in the cosmic neighborhood of the earth and the sun of quite specific cosmic structures.

In order to find the form and nature of these objects, we must above all establish what kind of material will be used for them and what space fields will act on them. This is valid in equal measure both for the earth architecture we are accustomed to and for the as yet unseen architecture of space. Doubtless, a key role in space, just as on earth, will be played by materials, that is, matter constructed of atoms and molecules. First of all, here we must mention synthetic materials and metals produced in earth conditions and brought into space from earth onboard rockets. With increasing mastery of space by man, to these materials will be added materials produced directly in outer space. The raw material for these products will primarily come from meteor bodies and asteroids. The energy required to process this raw material will be extracted from solar radiation or supplied from earth, in particular, using narrowly-directed radiation of lasers.

Multilayer thin-film structures consisting of systems of shells filled with gas at some pressure must gain wide acceptance in outer space. For example, extremely large mirrors to collect light and short radio waves can be made of metallized synthetic films forming a membrane between two thin-film spheres. In one of these spheres the pressure can be somewhat greater than the other. This makes it possible to impart any desired curvature to the mirror-membrane. Perhaps, as we can see from Fig. 1, there are other solutions for designing a thin-film convex mirror. /346

Often certain forces stretching a structure can appear in outer space. In these conditions various kinds of synthetic filaments and ribbons of organized molecular structure (monocrystals and so on) and, owing to this structure, possessing extremely high tensile strength will find wide application.

From this it follows that various gases will be an essential component in space structures. These gases must exhibit weak diffusibility through the films in which they would be enclosed. Therefore, gases consisting of large molecules will evidently be employed. Since in outer space the weight of systems in several cases is not of significant importance, it is possible that the gases will be replaced with liquids in appropriate conditions.

In addition to matter, a key element in cosmic structures must be electromagnetic radiation. This sounds unusual from the standpoint of traditions in earth architecture. However, one can scarcely doubt that narrowly directed beams of lasers and radio relay shorwave lines will become an inseparable part of cosmic structures. We can consider as examples of these structures of electromagnetic cosmic architecture, for example, systems of radio beams providing for the directed flight of rokcets (Fig. 2). It is highly probable that using these laser beams special light pipes can be produced in order to transmit vapors and gases through outer space. These pipes must also become highly effective components of cosmic architecture (Fig. 3).

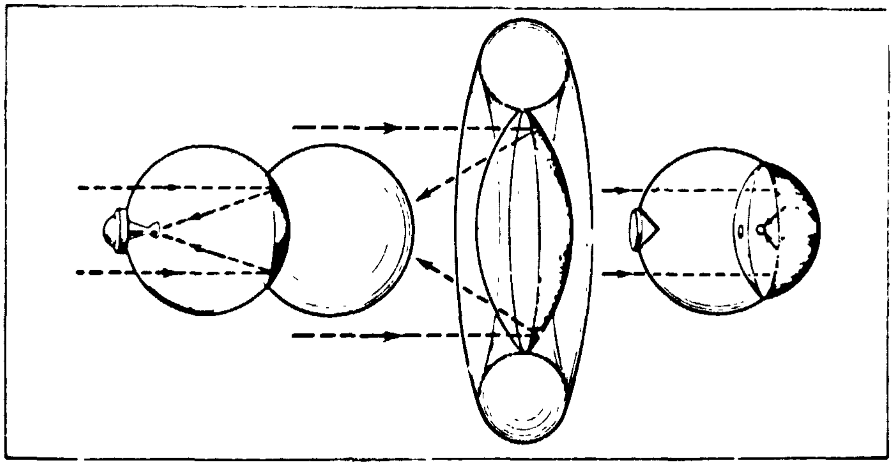

Fig. 1. Thin-film pneumatic convex mirrors

Fig. 2. Zones of directed radiation of radio waves controlling rocket travel /347

Various dangers threaten cosmic structures. They are exposed to irradiation amounting to high intensities during chromospheric flares on the sun; highly energetic ultraviolate rays act on them. Even more dangerous for cosmic structures are meteoric bodies travelling near the earth at speeds from 11 to 70 km/sec.

Impacts even of quite neglible meteoric particles can inflict great damage, since they resemble explosions of small charges of superpowerful explosives. If a meteoric particle encounters a massive barrier, it will disintegrate upon penetrating this barrier along a path whose length is close to the particle size.

However, here the ambient medium will become intensely heated, partially melt and vaporize, and exert tremendous pressure on the surrounding mass. As a result, a broad but shallow funnel resembling lunar craters in shape is formed. In these conditions a meteoric particle of small size can become entirely atomized and disintegrate, when a relatively thin film is placed in its path. True, the film will be punctured if this happens. But if it is arranged in the form of a shield in front of another film of the same kind, the second film will be protected (Fig. 4). Therefore, protection against fine meteoric particles can be provided by multilayer film structures.

In order to eliminate openings in the external film, which from time to time will arise when there are meteoric impacts, self-stretching materials of the type used in protecting fuel tanks on aircraft can be used. Protection against larger meteoric bodies can be assumed to be not particularly necessary because the probability of impacts of such bodies, as we know, is very small.

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Fig. 3. Light pipe producted by a laser through which gas can be transmitted across outer space

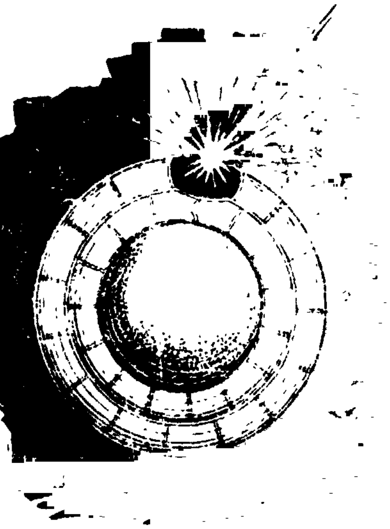

Fig. 4. Thin-film multilayer protection against fine meteoric bodies

However, protection is possible even in this case. In particular, long-range radar observation of the approach of large meteoric bodies can be provided, along with automatic devices permitting swerving from encounter with such a body by means of a short maneuver.

Moreover, large space structures can be provided with sectionalized compartments and redundancy of structural connections that would preclude damage to the major structure as a whole even if some part of it were struck by a large meteoric body. Obviously, the techniques of performing subsequent repair in the future can become highly effective and fast-acting.

If we turn to architectural and engineering structures built by various people in different historic times on earth, we can establish that they all must very strictly and consistently make allowance for the force of gravity. This shows up, in particular, in strict verticality of the axes of symmetry of architectural structures, as well as their parts (columns, windows, doors, and so on).

It is also absolutely necessary that architecture in space takes strict account of the action of cosmic force fields. Such /349
fields can be produced in different cases. The simplest example can be an interplanetary station consisting of two sections connected by a more or less long cable. A station of this type will rotate about its common center of gravity, and as a result each of these sections will be subject to centrifugal forces that can replace the ordinary gravity force by producing within the sections convenient conditions for prolonged occupancy by astronauts. Stations of this type can be symmetrical, asymmetrical, or else circular (Fig. 5).

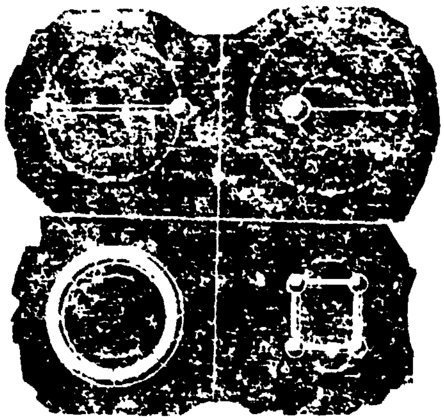

Fig. 5. Kinds of space stations

The simplest systems of this kind are conveniently referred to as linear. If a system of this kind will begin to travel as a satellite in a circular orbit around the earth or some other celestial body, then so-called tidal-forming forces will act on this system (in spite of the fact that the center of gravity of the system exists in conditions of complete weightlessness).

These forces act so that any part not in the plane of the orbit tends toward this plane. Furthermore, any body beneath the center of gravity will tend to descend even further while a body above the center of gravity will tend to ascend even higher. The force lines of the tidal-forming field constitute a system of branches of hyperbolas line in vertical planes perpendicular to the orbital plane (Fig. 6).

Fig. 6. Force lines of a field of tidal-forming (tidal) forces

Considering the action of tidal-forming forces, it can be suggested that future large orbital stations moving around the earth and other celestial bodies (for example, the moon) will have a major axis that is vertically elongated (along a line passing through the center of the celestial body). The mean axis of this station /350
will lie in the orbital plane, and the smallest of the axes will be disposed perpendicular to the orbital plane. Here connections functioning in tension (guy structures) must be in the vertical direction. Light connections immobilizing the shape of the structure but not bearing any load are necessary in the orbital plane. Connections functioning in compression are needed in directions

perpendicular to the orbital plane. These connections must exhibit the requisite resistance to shear in order not to lose stability upon compression.

Of course, the tidal-forming forces are not large. They are as many times weaker than the force of gravity as the distance from a given part from the center of mass of the entire system is smaller than the orbital radius. Therefore, cosmic orbital stations can attain very large dimensions, extending to hundreds of kilometers in the vertical direction. If these stations move in the manner of a ship's wake along a circular orbit, they will always be at unchanged distance one from the other. Therefore no difficulties can arise when they are connected.

By this method tremendous orbital objects having the shape of an arc with its center at the center of the celestial body attracting them can be built. Ultimately, this arc (or several arcs constructed in the same orbit) will close into a ring located in the corresponding orbit. A good many of these orbital rings can be built, by using various altitudes above the earth's surface. The rings and their systems evidently must be regarded as one of the classical forms of future space architecture formed with objective regularity, more obvious and splendid than a Doric column or a Roman arch.

In the future, individual orbital rings will probably multiply and, upon increasing in size, will move away from the celestial bodies that were enveloped by them. Planetary rings will emerge -- situated around the sun or other stars in planetary orbits. As the number of these rings is increased, they will completely seal the star they surround from external observers. In this way the so-called Dyson sphere can be built, trapping completely high-temperature radiation of the star and transforming it into low-temperature infrared and short-wave radio emission. When this transformation is achieved, the radiation energy can be utilized for various complicated technological and biological processes essential to highly developed civilization.

Evidently, in the foreseeable future mankind will not yet be able to carry out such tremendous cosmic projects. However, this does not at all mean that the problem of their construction is not urgent. Rather, it is precisely today when experimental facilities in astrophysics are being developed incredibly rapidly, that we can set up the task of searching for the objects described in the limitless reaches of outer space. These objects must be understood as large celestial bodies at low temperature and extremely low density.

If superlarge and superrarefied cosmic bodies at low temperatures are found anywhere in space, then we must reckon with the possibility that we are encountering objects of the Dyson sphere type constructed of orbital rings and having a shape of a kind of helix. /351

Building the enormous cosmic structures, in spite of their extraordinary lightness, requires enormous amount of appropriate construction materials. These materials can be extracted most conveniently from asteroids and small planets because in this case a minimum of energy is required to move the material into outer space. It is desirable to use material of small celestial bodies which travel in orbits around the corresponding central body (the sun or the star) at a distance equal to about the radius of the orbital ring under construction. In these conditions minimum energy is required to give the necessary velocity to the parts of the orbital ring in order that they can enter uniformly into the makeup of this ring.

Refining material must be carried out mainly by using the concentrated light of the central star. In particular, it is possible to transform the radiation flux using lasers.

The main chemical elements that will be used evidently will be those that are the most widespread in outer space, that is, iron, silicon, and oxygen. The nuclei of atoms of these chemical elements are thermodynamically most stable and this accounts for their predominance in the universe. Science thus far has not yet built material for cosmic structures based on the synthesis of iron, silicon, and oxygen. At present it is premature to estimate how soon this problem will be solved.

Perhaps, we can assume it to be highly probable that building structures out of iron and silicon in space is wholly possible and predictable. It is not precluded that monocrystalline wires, ribbons, and films will be built of these chemical elements.

Constructing monocrystals of iron oxides whic ould be prepared in considerable quantity from the cosmic erves of oxygen and iron represent a complicated and thus far unclear problem.

Life emerged and developed on the surface of the earth in its atmosphere and hydrosphere. It is probable that life emerged and developed also on several other celestial bodies, perhaps very far removed from our corner of the universe. It is improbable that highly organized intelligence would limit its activity only to the atmosphere and hydrosphere of the planet that gave its birth. It is more probable that in the search for freedom for its creativity, advanced intelligence as an expression of highly organized matter would break out into the void of space and begin to fill it with tremendous structures made of matter, light, and electromagnetic waves of various wavelengths. Doubtless, electrical and magnetic fields, and also possibly controlled gravity fields and waves will be regularly used in these structures.

SPACE FLIGHTS AND QUESTIONS OF LAW /352

E. Pepen, President of the International
Institute of Space Law (France)

Even before the launch of the first earth satellite on 4 October 1957, jurists had addressed themselves to problems arising from the exploration and use of outer space via satellites. However, articles written in the "pre-Sputnik" period and the exchange of opinions during this time involved primarily theoretical problems, such as the limits to national sovereignty in the near-earth space.

But soon Soviet and American advances in mastering space compelled jurists to deal with more concrete problems resulting from advances in a new science -- astronautics. International and national organizations of jurists studied and discussed juridical aspects of space flights, and the results of their investigations were placed at the disposal of international agencies.

Recognizing the vital importance of international cooperation in the study and use of outer space, the UN General Assembly set up a Special Committee on Peaceful Uses of Outer Space on 13 December 1958, and to a list of technical problems to be examined added the study of legal problems that may arise during the carrying out of programs on the exploration of outer space.

On 20 December 1961 the UN General Assembly adopted the first legal principles recognized as regulating the actions of nations in the exploration and use of outer space:

international law, including the Charter of the United Nations Organization, is extended to outer space and celestial bodies; and

outer space and celestial bodies are accessible to exploration and use by all nations in accordance with international law and are not to be appropriated by nations.

In this same resolution, the UN General Assembly, recognizing that the United Nations must be the center of international cooperation in the exploration and use of outer space for peaceful purposes, requested that nations launching objects into outer space make available to the United Nations necessary information for accessible registration of launches.

In March 1962, at the first session of the Juridical Subcommittee of the Permanent UN Committee on the Peaceful Uses of Outer Space, it became necessary to supplement the above-mentioned two basic principles of the resolution.

Simultaneously with recognition of the priority in studying the two most important problems -- providing assistance to astronauts and spacecraft and responsibility for damage incurred as the result of space activity, the Soviet delegation presented to the Juridical Subcommittee a draft Declaration of Basic Principles on the Activity of Nations in the Exploration and Use of Outer Space for all nations of the world to sign. At following sessions, documents with the list of the basic principles were presented by the United Arab Republic, Great Britain, and United States. /353

First of all, it was necessary to resolve a question about the fundamental juridical principles. In 1963 the Committee and its Juridical Subcommittee broadly discussed not only the contents of the principles, but also the form that the document must take -- an agreement signed by nations, or a resolution of the UN General Assembly. However, at that time no agreement on a single text was arrived at. In 1963 a compromise text was prepared and offered for consideration by the UN General Assembly, and unanimously approved by it -- the solemn Declaration of Legal Principles regulating the activity of nations in the exploration and use of outer space, dated 13 December 1963. However, it did not satisfy all nations; some of them regarded the declaration only as an ordinary recommendation.

So the UN General Assembly recommended to the UN Committee on the Peaceful Uses of Outer Space to examine the question of incorporating the principles in appropriate international agreements.

The 1963 Declaration of Legal Principles is a reasonable compromise intended to unite and not divide members of the United Nations organization, and also as a new expression of international cooperation in space matters, supplementing the unanimously adopted resolution of the UN General Assembly dated 17 October 1963 which forbids placement of nuclear weapons in outer space. It solemnly called upon all nations to restrain from launching into near-earth orbit any objects containing nuclear weapons or other forms of weapons of mass destruction, placing them on celestial bodies, or placing them in outer space in any other manner whatever and, finally, to restrain from inciting, encouraging, or any kind of participation in the above-mentioned activity.

The Declaration of Legal Principles dated 13 December 1963 confirms and refines the principles of the exploration and use of outer space presented in the 20 December 1961 UN General Assembly resolution. The principle of freedom of exploration and use of outer space and celestial bodies by all nations based on equality remains the basic principle, however given the condition that:

the exploration and use of outer space are carried out for the good and for the interest of all mankind;

the activities of states in the exploration and use of outer space must be carried out in accordance with international law, including the Charter of the United Nations Organizations, in the interest of peace and security and progress in international cooperation and mutual understanding; and

in exploring and using outer space, nations must be guided /354
by the principle of cooperation and mutual assistance and must carry out all their activity in outer space with due recognition of appropriate interests of other states.

The declaration also confirms a principle in accordance with which outer space and celestial bodies are not for national appropriation, and it is made more exact that this appropriation must not be carried out either by the declaration of sovereignty over outer space and celestial bodies, nor by their use or occupation, nor by any other means.

The remaining articles of the Declaration contain a brief presentation of the principles that will be expanded and given more detailed presentation in subsequent conventions.

Assistance to astronauts and spacecraft in the event of distress and their return were at the focus of attention by interested nations from the very beginning of the space age. The Declaration of Legal Principles also deals with this problem, specifying that rights of property of space objects launched into outer space and constituent parts remain in force during their time in outer space and on their return to earth. These objects or their constituent parts, on being found beyond the territory of the nation in whose registry they are entered must be returned to this nation: it is obliged to present information about recognition data in advance.

All nations must consider astronauts themselves as emissaries of mankind into outer space and must render to them all possible assistance in the event of accident, distress, or forced landing on the territory of a foreign country or in the high seas.

Astronauts on completing a forced landing must be kept secure and returned at once to the nation in whose registry their spacecraft is entered.

Responsibility for damage inflicted by space activity today is not a theoretical problem. Space objects and their constituent parts, on falling to the earth, can inflict damage. For example, in November 1960 several cows in the area of the village Olgin in Cuba were killed by fragments of an American rocket. Falling rocket fragments have been often found in Canada, the United States, and the Union of South Africa. As the number of objects (rocket stages, satellites, and fragments) travelling in outer space and capable of falling on the earth over a more or less prolonged period of time is increased, doubtless the danger of their collision either with other space objects or with aircraft in the air will rise.

The 13 December 1963 Declaration establishes the general principle of responsibility for damage inflicted by space activity, for which each state carrying out or organizing the launch of an object into outer space and also each state from whose territory or installations an object is launched bears international responsibility for damage inflicted by the object or by its constituent parts on earth, in the air, or in the outer space for /355
a foreign government.

This general presentation of the Declaration of Legal Principles must be supplemented with an international convention. It must be determined what is understood by the term "damage" (material, moral, financial, and so on), what is the nature of the responsibility, and what of the circumstances precluding or mitigating it. Should a limit to responsibility be established? How is it to be distributed in the event of joint space activity of several states?

Who bears the responsibility if the launch of the spacecraft is undertaken by an international organization? The 1963 Declaration limits itself only to stating that "responsibility for implementation of the principles of this declaration is borne, in addition to the international organization, also by the nations participating in it." Does this provide joint responsibility for such cases? We must also determine the precise rules of procedure in order for an injured party to know how to receive reimbursement for the damage it suffered.

Besides the two above-mentioned essential legal problems with which two special international agreements deal, the Declaration of Legal Principles also discusses other problems, which doubtless also require international conventions, in particular, a principle binding states to carry out their activity in outer space with due recognition of the appropriate interests of other states (here the coverage refers to specific experiments which in the past raised objections from several scientists, in particular astronomers interested in the use of outer space). The

Declaration provides in general outline for some agreement on the basis of which a nation having reason to assume that its activity in outer space or an experiment planned by it or by its citizens will pose potential harmful interference for the activities of other states in the peaceful exploration and use of outer space, before beginning the activity or the experiment, must seek appropriate international consultation.

On the other hand, a nation having a reason to assume that activity in outer space or an experiment planned by another nation, will pose potentially harmful interference to activity in the peaceful exploration and use of outer space, must request that consultation be held relative to this activity or this experiment. However, this somewhat foggy text of the Declaration does not provide for any procedures for the appropriate consultations and does not define to what extent nations are obligated to take account of their findings.

The Institute of International Law in Brussels and the David Davis British Institute for the study of international problems has given serious attention to the more general obligation not to inflict harm to the interests of all mankind by carrying out certain experiments. They have emphasized the danger that lies in any changes on earth or in celestial bodies, in their ambient space, or in outer space that results from the spreading of elements capable of disturbing the equilibrium in /356
nature, for example,changing climate or meteorological conditions in certain regions. To prevent this kind of experiment, the British Institute then formuluted various resolutions and sanctions. Doubtless, concluding a convention on this problem will be just as necessary as on the question of preventing biological, radiation, and chemical contamination of outer space and celestial bodies with craft launched from the earth, or vice versa.

The future construction of inhabited scientific stations first on the moon, and then also on other celestial bodies will pose the problem of the necessity for studying their legal status. Doubtless, if we bear in mind the general principles of the 1963 Declaration, we see that the construction of these stations cannot serve as a justification for the appropriation of the moon or other celestial body, or even small parts of it where they are located. The David Davis Institute on the study of international problems proposed that these stations be placed as soon as possible under the control of the United Nations Organization. Before this is done, the nation building or permitting its citizens to build such a station must exercise jurisdiction over all persons living there and also over the section of the surrounding surface necessary for the utilization and maintenance of the station.

In the event that two stations belonging to different states are erected on the same celestial body in close proximity, the need arises for appropriate demarcation of the competence of each of them, without even referring to the necessity of adopting other measures, in particular, measures to prevent possible mutual interference during periods of radio communications with earth.

The problem of the juridical status of moon or planetary stations, and also orbital stations is an urgent problem that must be studied, just as the legal status of orbital space stations. /357

Other legal problems have arisen or will arise resulting from advances in radio communications using satellites. This means of communications is of unquestioned interest not only as a supplement and facilitation of ordinary means of communications, but also as a method for rapid dissemination of enlightenment and advances in cultural exchange. However, these means of communications require a new legal body of regulations, especially when radio broadcasting and television programs from one place on earth will be picked up by satellites directly in another.

Even at the present stage of radio communications, numerous difficulties of a legal nature are being outlined, which must be solved in the future. Some of them have been indicated at a conference of experts on space communications and information facilities, held in December 1965 in the UNESCO building. They are brought about, in particular, by the differing bodies of regulation for the use of satellites in transmitting and receiving countries, different laws of these countries relating to the spreading of false rumors, different kinds of protection of the rights of authors depending on whether or not a certain nation is a participant in an international convention, and different attitudes toward the question of the use of broadcasts for advertising purposes. Arranging programs for transmission to all countries of the world requires an appropriate body of regulation which must not, in particular, upset existing provisions.

In its presentation, the Declaration of Legal Principles dated 13 December 1963 is reminiscent of the applicability to outer space of the 3 November 1947 resolution of the UN General Assembly condemning propaganda aimed at or capable of causing or intensifying the threat to the peace, violation of peace, or acts of aggression.

With further progress in the mastery of outer space, new legal problems will be added to those which have been discussed above and which must be solved with broad international cooperation. Law cannot and must not lag behind scientific-technical progress.

PRACTICAL AFFAIRS IN SPACE LAW /356

G. P. Zhukov, Doctor of Juridical Sciences

On 27 January 1967 the Agreement on the Principles of the Activity of the Nations in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, developed on the initiative of the Soviet Union, was signed in Moscow, Washington, and London; all the provisions of the 1963 Declaration of Legal Principles are included en toto in this Agreement. The Agreement on Outer Space took effect on 10 October 1967. Most countries of the world participate in it.

Further advances in astronautics require making more concrete and extending the provisions of the Outer Space Agreement of 1967 as applied to the legal status of the moon. Accordingly, in 1962 a text of the special Agreement on the Moon was developed within the framework of the United Nations; the basis of this agreement was a draft first presented to the United Nations by the Soviet Union in 1971. In addition, in 1968 an international agreement on rescuing astronauts was concluded, and in 1972 a convention on international responsibility for damage caused by space objects was drawn up.

WHO OWNS THE MOON? /358

G. P. Zhukov, Doctor of Juridical Sciences,
Vice President of the International Institute
of Space Law

Major advances in astronautics have signalled the approach of the time when manned space flights to the moon will become an everyday phenomenon. Therefore even today it is important to have a clear idea of whether the moon can be possessed, and if not, then what can and what cannot be done on it, or in other words, what is the legal status of our natural satellite. At the present time in general jurists have not discussed the question of whether the moon can be possessed and what is required for this. According to the Outer Space Agreement dated 27 January 1967, the moon, just as other celestial bodies, is not available for national appropriation. It cannot be appropirated either by proclaiming sovereignty over it, or by use or occupation, nor by any other means (article II of the Agreement). The Agreement spells out quite clearly the right of free access to the moon for all nations. And its exploration and utilization must be carried out for the good and in the interests of all countries and it is viewed as an achievement for all mankind (article I of the Agreement).

Thus, we can answer the question as to who owns the moon with the following -- all of mankind.

The Outer Space Agreement gives us also the possibility of dealing with the question of what can and what cannot be done on the moon.

First of all, it is forbidden to set up military bases, structures, and fortications on the moon, to test any kinds of weapons, including nuclear, or to carry out military maneuvers (article IV of the Agreement).

However, it is not forbidden to utilize military personnel for scientific exploration or any other peaceful purposes. It is also not forbidden to use any equipment or means necessary for the peaceful exploration of the moon.

This qualification is explained by purely practical considerations. It must be clear to everyone that the courage, stamina, and also the excellent preparation and instruction of military pilots is the reason why as a rule astronauts are selected from their ranks. At the same time the peaceful or military nature of activity in general, and on the moon in particular, depends not on whether this activity is carried out by civilian or military personnel, but on the goals which are pursued in each specific case. In fact, no one would conceive of calling the actions of a military pilot in providing assistance to the population of an area suffering from a natural disaster a "nonpeaceful" action.

Still, it is very important that the reservation in the Agreement on the possible use of military personnel and also any equipment is not a loophole to use the moon for military purposes. In fact, the moon, according to the Outer Space Agreement, just as other celestial bodies, must be used exclusively for peaceful purposes. /359

The freedom of access to the moon for all nations does not give the right to a single nation to act to the detriment of others. Therefore, if objects of one nation on the moon or its citizens living there are harmed, then the nation inflicting the harm bears international responsibility for this (article VII of the Agreement).

States must carry out their exploration and utilization of the moon "with due recognition of appropriate interests of other states" (article IX of the Agreement). In particular, here the intention is to avoid harmful contamination of the moon and also unfavorable changes in the earth environment resulting from bringing back lunar matter. In May 1964 the Executive Council of the Committee on Space Research (COSPAR), International Council of Scientific Unions adopted a special resolution based on a paper given by its consultative group on questions of potentially dangerous consequences of experiments conducted in outer space. In particular, the resolution noted that in a moon landing there is no necessity of carrying out the same kind of careful sterilization of space objects as in a flight to Mars. The consultative group based its conclusion on the assumption that conditions on the surface of the moon preclude the possibility of the propagation of microbes. An exception can be represented, in its view, by drilling rigs on the moon which therefore must desirably undergo careful sterilization. This must prevent contamination in the deep layers of the lunar surface where a more favorable environment for microbial propagation can exist.

However small the possibility of microorganisms being present on the moon, scientists still gave thought to preventing their possible harmful effect on earth forms of life. Accordingly, appropriate measures were proposed for the disinfecting of spacecraft returning from the moon, all spacecraft contents, above all hermetic containers enclosing lunar samples, and astronaut pressure suits. It is proposed that after ground landing (or splashdown), astronauts be kept in quarantine for several weeks, as well

as the members of the special team disinfecting the spacecraft. It was suggested that containers bringing samples back from the /360
moon be opened with all precautionary measures adopted. Some scientists went even further and proposed that all of the above-mentioned objects be inspected at a space quarantine station. They maintained also that the first and the most critical examinations of samples taken from space should best be done not on earth, but in a specially equipped laboratory on the spacecraft.

However, life failed to confirm the fears of the scientists. American astronauts having visited the moon were not subjected to a quarantine here on earth, and as for the lunar samples brought back to earth, no special precautionary measures were taken.

Given the full importance of the Outer Space Agreement, it cannot but be noted that in view of its general character it does not provide an answer to all the problems which will arise with further mastery of the moon. Doubtless, with time problems associated with the flight of people to the moon, with the return flight, with their residence at scientific research stations, with their interrelationships and activity will require legal regulation.

In accordance with the Outer Space Agreement dated 27 January 1967, states retain the right of property over space objects sent by them to the moon or constructed there, and also execute control and jurisdiction over these objects and any of their crews (article VIII of the Agreement).

A space object on the moon can be built up of materials brought to the moon from the earth, from local lunar raw material, and also from both kinds of materials. The Outer Space Agreement does not provide any reservations regarding the legal status of stations erected on the moon using local raw material. Therefore these stations can quite properly be included in the national /361
register of the nations constructing them. Arguments of some authors to the effect that this inclusion will contradict the provision of the Agreement on forbidding national appropriation of the moon do not have serious grounds.

At international colloquia on space law there has also been discussion of the question of what is to be done with a station abandoned on the moon? Should it be occupied and used by other country? Can it be transferred or demolished? It appears to us that an abandoned station in principle continues to remain the property of the country that built it on the moon. Only in the event of the clear denial of the property-owing state of its rights to this station or other equipment can they be regarded as so-called owner-less property.

A state constructing a scientific research station or a settlement on the moon, in virtue of its responsibility for everything that happens there, doubtless must possess jurisdiction not only with respect to its citizens at the station, but also, as it appears to us, also with respect to citizens of other states present there. Of course, this does not preclude the fact that if interested states deem it more appropriate to adhere exclusively to the principle of personal jurisdiction, they are justified in concluding the relevant agreement. It is possible that experience will prompt the advisability of establishing different legal status for foreign citizens included in the composition of permanent personnel at a station and persons visiting a station for short periods of time.

It must be remembered that the Outer Space Agreement refers to jurisdiction and control over any crew of a space object. Here the Agreement does not make distinctions between jurisdiction exercised by a state with respect to an object launched into outer space and an object brought to or erected on a celestial body.

Exclusively personnel jurisdiction of a state over its citizens will operate on the moon beyond the bounds of stations. In the event of a dispute concerning the exercise of jurisdiction on the moon, it is useful to turn to the Agreement on the Antarctic, which provides that when such a situation exists the parties are obligated to immediately consult with each other to arrive at a mutually acceptable decision. /362

As individual countries build new stations on the moon, it is possible that the necessity for concluding special international agreements for regulating questions that arise will appear.

The dangerous solar flare prediction service will have vital importance for astronauts landing on the moon, as well as timely warning about a rise in radiation caused by an unexpected flare on the sun. In this respect, vital importance attaches to the obligations stated in the Outer Space Agreement on immediate exchange of information between states when they detect phenomena in outer space, including on the moon and other celestial bodies, that could represent a danger to the life or health of astronauts (article V of the Agreement).

Severe and unusual conditions which man will inevitably encounter on the moon will require establishing there the broadest contacts and cooperation between representatives of different countries. These contacts must provide mutual assistance to each other and prevent the conducting of experiments that could bring about harmful interference with the activity of any other station on the moon (for example, its radio communications with earth).

Further mastery of the moon possibly will require setting up a special rescue service.

In addition to the right to build stations on the moon, every country has the right to utilize the moon's natural resources. This right can include the following: 1) exploration, extraction, and processing of mineral and other natural resources of the moon; /363
and 2) their utilization and processing for local needs and possibly also for export to earth.

The recognition by individual countries of the rights for the utilization of the moon's natural resources can in no wise mean the recognition by them of the right of national appropriation of the moon. The moon must remain open for exploration and use by other states based on equality and in accordance with international law. Bringing in lunar samples to earth is one of the forms of scientific exploration of the moon.

During the further mastery of the moon, many problems will rise that will require coordination and cooperation between the efforts of interested countries. In particular, this can include constructing and operating spaceports, distribution of energy resources, mutual assistance in the event of distress, exercising of jurisdiction, providing communications and utilities in lunar conditions, exploitation of minerals, conservation of natural resources, cooperation in scientific research and scientific collaboration, exchange various kinds of data of importance tance for persons living on the moon, and also many other questions which are difficult to foresee ahead of time.

SEVERAL ARTICLES OF THE OUTER SPACE AGREEMENT

Article I

Exploration and use of space, including the moon and other celestial bodies, is to be carried out for the benefit and in the interest of all people, regardless of the degree of their economic and scientific advancement, and is an attainment of all mankind.

Outer space, including the moon and other celestial bodies, is open for exploration and utilization by all countries without any discrimination whatever, based on equality and in accordance with international law, with free access to all areas of celestial bodies.

Outer space, including the moon and other celestial bodies, is free for scientific investigation and states will cooperate and encourage international collaboration in these investigations.

Article II

Outer space, including the moon and other celestial bodies, must not be subject to national appropriation either by proclaiming sovereignty over them, or by utilization or occupation, or any of the means.

Article IV

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States that are participants in the agreement are obligated not to launch into near-earth orbit any objects consisting of nuclear weapons or any other means of mass destruction, must not establish such weapons on celestial bodies, and must not permit such weapons into space by any other means.

The moon and other celestial bodies are to be used by all states that are participants in the agreement exclusively for peaceful purposes. It is forbidden to set up on celestial bodies military bases, structures, and fortifications, to test any kinds of weapons, or to carry out military maneuvers. The use of military personnel for scientific investigations or any other peaceful purposes is not forbidden. It is also not forbidden to use any equipment or means essential for peaceful exploration of the moon and other celestial bodies.

Article V

States that are participants in the agreement are to regard astronauts as emissaries of mankind into outer space and are to provide them with all possible assistance in the event of accident, distress, or forced landing on the territory of another country that is a participant in the agreement, or in the high seas. Astronauts who make a forced landing must be maintained in /361 security and must be immediately returned to the country in whose register their spacecraft is listed.

When carrying out activity in outer space, including on celestial bodies, astronauts of one country that is an agreement participant will provide assistance to astronauts of other countries that are participants in the agreement.

Countries that are participants in the agreement must immediately inform other countries that are participants in the agreement or the General Secretary of the United Nations on their detection of phenomena in outer space, including the moon and celestial bodies, which could represent a hazard to the life or health of astronauts.

Article IX

During exploration and utilization of outer space, including the moon and other celestial bodies, countries that are participants in the agreement must be guided by the principle of cooperation and mutual assistance and must carry out all their activity in outer space with requisite consideration of the appropriate interests of all other countries that are participants in the agreement. Countries that are participants in the agreement are to undertake the study and exploration of outer space in such a way as to avoid its harmful contamination, and also unfavorable changes in the earth environment due to the return of extraterrestrial matter, and also so as to take appropriate measures, in the event that they are necessary. If any country that is a participantsin the agreement has reason to assume that the activity or experiment planned by this country that is a participant in the agreement or by the citizens of this country will pose potential harmful interference with the activity of other countries in the peaceful exploration and utilization of outer space, then it must engage in appropriate international consultation before it begins this activity or this experiment. A country that is a participant in the agreement, having reason to suppose that the activity or experiment planned by another country that is a participant in the agreement in outer space will mean potentially dangerous interference with the peaceful exploration and utilization of outer space, including the moon and other celestial bodies, must request that consultation be taken relative to this activity or experiment.

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The bibliography includes scientific and, in part, popular-scientific literature on the problems highlighted in the articles in the collection: essentials of life, cosmic influences on life on earth, the possibility of life in the universe, extra-terrestrial civilizations and contacts with them, prospects for mastery of outer space, and space law. The literature list is compiled by divisions of the collection and within divisions -- in alphabetic order by the authors' last names.

The bibliography covers literature published mostly in recent years by various publishing houses, including Nauka, Naukova Dumka (in Russian), Znaniye, Mashinostroyeniye, and so on. Literature in translation is also included.

Literature on problems of astronautics proper is represented by a few, mainly generalizing publications. The latest achievements in space biology and medicine associated with the first space flights are represented by several of the most significant works of a scientific and popular-scientific nature.

Besides books and booklets, the problems covered in the collection are treated in various periodical publications of both a scientific and popular-scientific character. They include the following journals: Zemlya i Vselennaya /Earth and the Universe/, Astronomicheskiy Zhurnal /Astronomy Journal/, Kosmicheskiye Issledovaniya /Space Studies/, Kosmicheskaya Biologiya i Meditsina /Space Biology and Medicine/, and Aviatsiya i Kosmonavtika /Aviation and Astronautics/. From 1958 to 1963, the publishing house of the Academy of Sciences issued 18 collections of Iskusstvennyye Sputniki Zemli /Artificial Earth Satellites/. The Kazakh SSR Academy of Sciences has published the Trudy Sektora Astrobotaniki /Transactions of the Astrobotany Sector/ (1953-1960, volumes 1-8).

The subject matter of this collection is reflected in popular-scientific journals and almanacs of a general nature -- Priroda /Nature/, Nauka i Zhizn' /Science and Life/, Tekhnika - Molodezhi /Technology for Youth/ Znaniye - Sila /Knowledge is Power/, Nauka i Chelovechestvo /Science and Mankind/, Khochu Vse Znat' /I Want to Know Everything/, and Budushcheye Nauki /The Future of Science/.

Articles on astronautics and related problems are included in the Bol'shaya Sovetskaya Entsiklopediya /Great Soviet Encyclopedia/ (second edition).

Since 1957, yearbooks of the BSE /Bol'shaya Sovetskaya Entsiklopediya/ have been published; in the section "Science and Technology" a treatment is presented dealing with Soviet and foreign space research, problems of astronomy, materials of all-union and international scientific congresses, conventions, conferences, and so on.

The Sovetskaya Entsiklopediya publishing house issued a one-volume popular encyclopedia Kosmonavtika /Astronautics/ (second enlarged edition, 1970), that includes materials on astronautics, modern space rocket technology, astronomy and geophysics, space biology and medicine, and space law. An appendix presents data on space vehicles launched in 957-1969 and an extensive bibliography in Russian and in foreign languages.

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